EXHIBIT C

STATE OF SOUTH CAROLINA) IN THE COURT OF COMMON PLEAS
) CASE NO.:
COUNTY OF BEAUFORT)

Jill Demark,

Plaintiff,

-vs-

Jetson Electric Bikes, LLC, and
Amazon.com, Inc.

Defendants.

COMPLAINT
(Jury Trial Demanded)

The Plaintiff complaining of the Defendants would respectfully show unto the Court that:

1. The Plaintiff is a resident and citizen of the County of Beaufort, State of South Carolina.

2. Defendant, Jetson Electric, upon information and belief, is a corporation organized and existing under the laws of the state of New York, but doing business in South Carolina, including the County of Beaufort, State of South Carolina.

3. Defendant, Amazon.com, Inc. (hereinafter “Amazon”), upon information and belief, is a corporation organized and existing under the laws of the state of Delaware, but doing business in South Carolina, including the County of Beaufort, State of South Carolina.

4. This court has jurisdiction over the parties and the subject matter.

5. That Defendant, Jetson Electric, is in the business of designing, manufacturing, and distributing Gyro Self Balancing Scooters.

6. That Defendant, Amazon, is in the business of selling and distributing goods, including the Gyro Self Balancing Scooters designed, manufactured, and distributed by Defendant Jetsonson Electric.

7. That Plaintiff is the owner of real property located at 66 Mroz Road, Beaufort, South Carolina.

8. That Defendant, Jetson Electric, designed, manufactured, and distributed a Gyro Self Balancing Scooter that was placed in the Plaintiff's real property.

9. That on September 27, 2017, a Gyro Self Balancing Scooter's battery pack overheated, resulting in a fire, which caused extensive damage to the Plaintiff's home.

10. It was later determined that the Gyro Self Balancing Scooter was constructed in a way that would cause the battery pack to facilitate thermal overrun, which caused it to overheat, which caused the fire.

<u>FOR A FIRST CAUSE OF ACTION</u>
(Negligence against Defendant Jetson Electric)

11. That each and every preceding allegation consistent with this cause of action is re-alleged.

12. That Defendant, Jetson Electric, owed Plaintiff a duty to design, manufacture and distribute the Gyro Self Balancing Scooter and its components free from defects so that its battery pack would not fail and cause a fire during normal use.

13. That Defendant, Jetson Electric, breached such duty by designing, manufacturing, and distributing the Gyro Self Balancing Scooter and its components in such a way that its battery pack would fail and overheat, thereby causing fire damage to the Plaintiff's property.

12. That the Plaintiff's damages directly and proximately resulted from the negligence, carelessness, and recklessness of the Defendant, Jetsonson Electric, in failing to design, manufacture and distribute the Gyro Self Balancing Scooter and its components free from defects and not subject to failure upon normal operating conditions.

FOR A SECOND CAUSE OF ACTION
(Negligence against Defendant Amazon)

13. That each and every preceding allegation consistent with this cause of action is re-alleged.

14. That Defendant, Amazon, owed Plaintiff a duty to distribute a Gyro Self Balancing Scooter and its components free from defects so that its battery pack would not fail and cause a fire during normal use.

15. That Defendant, Amazon, breached such duty by distributing the Gyro Self Balancing Scooter and its components in such a way that its battery pack would fail and overheat, thereby causing fire damage to the Plaintiff's property.

16. That the Plaintiff's damages directly and proximately resulted from the negligence, carelessness, and recklessness of the Defendant, Amazon, in failing to distribute the Gyro Self Balancing Scooter and its components free from defects and not subject to failure upon normal operating conditions.

FOR A THIRD CAUSE OF ACTION
(Breach of Express Warranty)

17. All of the preceding allegations consistent herewith are re-alleged.

18. That Defendants represented that the Gyro Self Balancing Scooter and its components to be used inside the Plaintiff's real property would be supported by an express warranty**.**

19. That as a direct and proximate result of the fire damage caused by the Gyro Self Balancing Scooter and its battery pack failing, the Defendants breached their express warranty.

20. As a direct and proximate result of Defendants' breach of warranty, the Plaintiff has been damaged as alleged above and is entitled to an award of actual and consequential damages pursuant to S.C. Code Ann. § 36-2-313 (1976 as amended).

FOR A FOURTH CAUSE OF ACTION
(Breach of Implied Warranty of Merchantability)

21. All of the preceding allegations consistent herewith are re-alleged.

22. Pursuant to S.C. Code Ann. § 36-2-314 (1976 as amended), Defendants warranted the Gyro Self-Balancing Scooter and its components would be merchantable and fit for ordinary purposes.

23. As a direct and proximate result of the failure of the Gyro Self Balancing Scooter and its battery pack to properly protect against overheating during the unit's ordinary use, the unit was not fit for ordinary purposes, and the Defendants thus breached their implied warranty of merchantability.

24. As a direct and proximate result of Defendants' breach of warranty, the Plaintiff has been damaged as alleged and is entitled to an award of actual and consequential damages**.**

FOR A FIFTH CAUSE OF ACTION
(Breach of Warranty of Fitness for Particular Purpose)

24. All of the preceding allegations consistent herewith are re-alleged.

25. The Defendants knew or had reason to know of the particular purpose for which the Gyro Self Balancing Scooter and its components was required under S.C. Code § 36-2-315 (1976 as amended), and the Plaintiff relied on the same.

26. The Gyro Self Balancing Scooter and its components failed to function for the particular purpose that the Plaintiff relied upon and therefore the Defendants breached their implied warranty of fitness for a particular purpose.

27. As a direct and proximate result of Defendants' breach of warranty, the Plaintiff has been damaged as alleged above and is entitled to an award of actual and consequential damages.

FOR A SIXTH CAUSE OF ACTION
(Strict Liability)

28. All of the preceding allegations consistent herewith are re-alleged.

29. The Defendants engaged in the business of designing, manufacturing, and distributing the Gyro Self Balancing Scooter and its components, and that the Defendants distributed such a product to be used in the Plaintiff's home as contemplated by S.C. Code § 15-73-10 (1976 as amended).

30. The Gyro Self Balancing Scooter and its components designed, manufactured, and distributed by the Defendants were defective when it left Defendants' control in that it was not reasonably safe for foreseeable uses since it malfunctioned and caused severe fire damage during the course of ordinary use.

31. The Defendants placed this defective and unreasonably dangerous Gyro Self Balancing Scooter and its components into the stream of commerce expecting to reach users and consumers without a substantial change in the product's conditions, and said product did reach Plaintiff in

substantially the same condition as when they were originally manufactured and sold by the Defendants.

32. That the Plaintiff's property was directly and proximately damaged by this defective product as alleged above.

33. That as a direct and proximate result of Defendants' designing, manufacturing and distributing defective products, the Plaintiff's property was damaged and she is entitled to an award of actual and consequential damages.

WHEREFORE, Plaintiff prays for judgment against the Defendants in a sum sufficient to adequately compensate her for her actual damages and consequential damages, for the costs of this action, and for such other and further relief as this Court may deem proper.

McDONALD, McKENZIE, RUBIN
MILLER AND LYBRAND, L.L.P.

BY: s./JOHN F. McKENZIE
SC Bar # 15994
ATTORNEY FOR THE PLAINTIFF
1704 Main Street
Post Office Box 58
Columbia, SC 29202
(803) 252-0500

Columbia, South Carolina

September 18th, 2020

IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF SOUTH CAROLINA
BEAUFORT DIVISION

Jill Denmark, Plaintiff, v. Jetson Electric Bikes, LLC and Amazon.com, Inc., Defendants.	C.A. No.: 9:20-cv-03706-MBS **ANSWER TO PLAINTIFF'S COMPLAINT ON BEHALF OF OF JETSON ELECTRIC BIKES, LLC**

NOW COMES Defendant, Jetson Electric Bikes, LLC, by its attorneys, answering the Plaintiff's Complaint, admits, denies, alleges, and shows to the Court as follows:

1. Answering paragraph 1, this answering defendant denies knowledge or information sufficient to form a belief as to the truth of the allegation contained therein and, therefore, denies and puts plaintiff to her strict proof thereon.

2. Answering paragraph 2, this answering defendant admits that it is organized and existing under the laws of the State of New York. As for the remaining allegations, it denies and affirmatively alleges that it is organized as an LLC, not a "corporation" as alleged.

3. Answering paragraph 3, this answering defendant denies knowledge or information sufficient to form a belief as to the truth of the allegation contained therein and, therefore, denies and puts plaintiff to her strict proof thereon.

4. Answering paragraph 4, this answering defendant denies knowledge or information sufficient to form a belief as to the truth of the allegation contained therein and, therefore, denies and puts plaintiff to her strict proof thereon.

5. Answering paragraph 5, this answering defendant admits that it distributes Gyro Self Balancing Scooters but denies the remaining allegations.

6. Answering paragraph 6, this answering defendant denies knowledge or information sufficient to form a belief as to the truth of the allegation contained therein and, therefore, denies and puts plaintiff to her strict proof thereon.

7. Answering paragraph 7, this answering defendant denies knowledge or information sufficient to form a belief as to the truth of the allegation contained therein and, therefore, denies and puts plaintiff to her strict proof thereon.

8. Answering paragraph 8, this answering defendant denies knowledge or information sufficient to form a belief as to the truth of the allegation contained therein and, therefore, denies and puts plaintiff to her strict proof thereon.

9. Answering paragraph 9, this answering defendant denies knowledge or information sufficient to form a belief as to the truth of the allegation contained therein and, therefore, denies and puts plaintiff to her strict proof thereon.

10. Answering paragraph 10, this answering defendant denies knowledge or information sufficient to form a belief as to the truth of the allegation contained therein and, therefore, denies and puts plaintiff to her strict proof thereon.

FOR A FIRST CAUSE OF ACTION
(Negligence against Defendant Jetson Electric)

11. Answering paragraph 11, this answering defendant realleges and incorporates herein by reference, as if fully set forth herein, the admissions, denials and allegations contained within preceding paragraphs.

12. Answering paragraph 12, this answering defendant avers that the issue of duty is a legal conclusion to which no response is necessary. To the extent a response may be necessary,

this defendant asserts that any duty Jetson Electric may have owed is consistent with and does not exceed the applicable duty of care owed under New York law. As to any remaining allegations contained in paragraph 12, this answering defendant lacks knowledge or information sufficient to form a belief as to the truth of those allegations and, therefore, denies the same.

13. Answering paragraph 13, this answering defendant denies.

12. Answering paragraph 12, this answering defendant denies.

FOR A SECOND CAUSE OF ACTION
(Negligence against Defendant Amazon)

13. Answering paragraph 13, this answering defendant realleges and incorporates herein by reference, as if fully set forth herein, the admissions, denials and allegations contained within preceding paragraphs.

14. Answering paragraph 14 this answering defendant denies knowledge or information sufficient to form a belief as to the truth of the allegation contained therein and, therefore, denies and puts plaintiff to her strict proof thereon.

15. Answering paragraph 15, this answering defendant denies knowledge or information sufficient to form a belief as to the truth of the allegation contained therein and, therefore, denies and puts plaintiff to her strict proof thereon.

16. Answering paragraph 16, this answering defendant denies knowledge or information sufficient to form a belief as to the truth of the allegation contained therein and, therefore, denies and puts plaintiff to her strict proof thereon.

FOR A THIRD CAUSE OF ACTION
(Breach of Express Warranty)

17. Answering paragraph 17, this answering defendant realleges and incorporates herein by reference, as if fully set forth herein, the admissions, denials and allegations contained within preceding paragraphs.

18. Answering paragraph 18, this answering defendant denies knowledge or information sufficient to form a belief as to the truth of the allegation contained therein and, therefore, denies and puts plaintiff to her strict proof thereon.

19. Answering paragraph 19, this answering defendant denies.

20. Answering paragraph 20, this answering defendant denies.

FOR A FOURTH CAUSE OF ACTION
(Breach of Implied Warranty of Merchantability)

21. Answering paragraph 21, this answering defendant realleges and incorporates herein by reference, as if fully set forth herein, the admissions, denials and allegations contained within preceding paragraphs.

22. Answering paragraph 22, this answering defendant denies knowledge or information sufficient to form a belief as to the truth of the allegation contained therein and, therefore, denies and puts plaintiff to her strict proof thereon.

23. Answering paragraph 23, this answering defendant denies.

24. Answering paragraph 24, this answering defendant denies.

FOR A FIFTH CAUSE OF ACTION
(Breach of Warranty of Fitness for Particular Purpose)

24. Answering paragraph 24, this answering defendant this a realleges and incorporates herein by reference, as if fully set forth herein, the admissions, denials and allegations contained within preceding paragraphs.

25. Answering paragraph 25, this answering defendant denies knowledge or information sufficient to form a belief as to the truth of the allegation contained therein and, therefore, denies and puts plaintiff to her strict proof thereon.

26. Answering paragraph 26, this answering defendant denies.

27. Answering paragraph 27, this answering defendant denies.

FOR A SIXTH CAUSE OF ACTION
(Strict Liability)

28. Answering paragraph 28, this answering defendant realleges and incorporates herein by reference, as if fully set forth herein, the admissions, denials and allegations contained within preceding paragraphs.

29. Answering paragraph 29, this answering defendant denies knowledge or information sufficient to form a belief as to the truth of the allegation contained therein and, therefore, denies and puts plaintiff to her strict proof thereon.

30. Answering paragraph 30, this answering defendant denies.

31. Answering paragraph 31, this answering defendant denies.

32. Answering paragraph 32, this answering defendant denies.

33. Answering paragraph 33, this answering defendant denies.

AFFIRMATIVE DEFENSES

As and for separate and affirmative defenses to the Plaintiff's Complaint, Defendant, Jetson Electric Bikes, LLC, allege and show to the Court as follows:

1. Plaintiff's Complaint in whole or part fails to state a cause of action. Specifically, Plaintiff, *inter alia*, fails to allege and cannot prove as part of its strict liability claim the existence of a safer alternative design for the Self Balancing Scooter. *Branham v. Ford Motor Co*., 390 S.C.

203, 221 (2010). Plaintiff's Complaint also fails to allege and cannot prove that the product that caused the injury was, at the time of the accident, in essentially the same condition as when it left the hands of Jetson Electric. *Rife v. Hitachi Constr. Mach. Co., Ltd.,* 609 S.E.2d 565, 568 (S.C. Ct. App. 2005).

2. The subject Self Balancing Scooter complied with all applicable national, state and local codes and standards at the time it was manufactured.

3. Plaintiff's strict product liability claims are barred, in whole or in part, by the *Restatement (Second) of Torts*, Section 402A, Comment g, limiting strict product liability to eliminate those situations when a product's condition is safe at the time of delivery, but "subsequent mishandling or other causes" make it harmful by the time it is consumed, placing the burden of proof on Plaintiffs to prove that the product or component was in a defective condition at the time it left the seller's hands. The subject Self Balancing Scooter was safe at the time of delivery, but was later improperly used by Plaintiff.

4. Any and all events, injuries, loss, damage and expenditures referred to in the amended complaint were directly and proximately caused and contributed to by the actions, carelessness and negligence of Plaintiff. The extent of damages sustained by Plaintiff, if any, should, therefore, be reduced in proportion to the negligence of Plaintiff in causing said injuries and/or damages.

5. To the extent that the defendants had a duty to warn, Plaintiff's claims are barred, in whole or in part, because the defendant provided adequate "directions or warnings" as to the assembly and use of the subject Self Balancing Scooter within the meaning of the *Restatement of Torts*, Section 402A, Comment j.

6. Any product supplied by this answering defendant was, after delivery, substantially modified, altered or changed so as to materially affect its characteristics such that these answering defendants are not responsible for the alleged defective nature of the product which allegedly caused injury or damages to Plaintiff.

7. Plaintiff's warranty claims and damages are subject to limitations, exclusions, disclaimers, or modifications of warranties as provided with the Self Balancing Scooter.

8. There is no privity between plaintiff and Jetson with respect to plaintiff's warranty claims.

9. The answering defendant is entitled to a set-off against any damage awarded to Plaintiffs for any and all payments made by any collateral source.

10. Jetson Electric was not given proper notice and was not afforded an opportunity to conduct an investigation at the property where the alleged damage occurred. Such actions constitute negligent or intentional spoliation of evidence, and Jetson Electric has been prejudiced by Plaintiff and/or other third parties' aforementioned spoliation of evidence. In the event that Plaintiff is found to have negligently or intentionally spoliated evidence, such spoliation should act as a bar to Plaintiff's claims.

11. As the facts have not been fully developed in this cause of action, this answering defendant reserves the right to plead and hereby specifically assert, to the extent applicable and justified pursuant to the facts of this case, the affirmative defenses of accord and satisfaction, contributory negligence, election of remedies, estoppel, release, res judicata, satisfaction, waiver, the failure of Plaintiff to mitigate damages or take reasonable steps to avoid damages, the failure of Plaintiff to exercise ordinary care, the bar of the statute of limitations, and any other matter constituting an avoidance or affirmative defense.

12. This answering defendant expressly reserves the right to assert or modify any defenses, affirmative defenses or otherwise, as might be established during discovery and by evidence in this matter.

WHEREFORE, Defendant, Jetson Electric Bikes, LLC, hereby demands judgment as follows:

a. Dismissal of the Plaintiff's Complaint on the merits and with prejudice, together with statutory costs, attorney's fees and reimbursements for the disbursements; and

b. For any other relief the Court deems just and equitable.

TRIAL BY A JURY OF ALL ISSUES TRIABLE TO A JURY IS HEREBY DEMANDED

HOWSER, NEWMAN & BESLEY, L.L.C.

By: /s/ Kelley Cannon
Kelley Shull Cannon (Federal Bar# 6789)
1508 Washington Street
Post Office Box 12009
Columbia, South Carolina 29211
(803) 758-6000
Attorney for the Defendant
Jetson Electric Bikes, LLC

November 25, 2020

CERTIFICATE OF SERVICE

The undersigned hereby certifies that a copy of this document was served on the 23rd day of November, 2020, upon all parties in the above cause by serving the attorneys of record at their respective addresses disclosed on the pleadings. Service was made by:

☐ U.S. Mail ☐ Hand-Delivery ☒ Email ☐ Facsimile ☒ Other – EDMS

Attorney for Plaintiff
John F. McKenzie, Esq.
McDonald McKenzie, Rubin,
Miller and Lybrand, LLP
1704 Main Street
Columbia, SC 29201
jackm@mmrml.com

Attorney for Amazon.com, Inc.
Phillip E. Reeves
Gallivan, White & Boyd, P.A.
PO Box 10589
Greenville, SC 29603
preeves@gwblawfirm.com

/s/ Chelsea M. Thorne
Chelsea M. Thorne, Legal Assistant

CORE ENGINEERING, CORP.
1000 Johnnie Dodds Boulevard, Suite 103-357 Mount Pleasant, South Carolina 29464
(843) 881-9522
Fax: (888) 789-1492
coreengineering.com

April 23, 2021

Jack McKenzie
McDonald, McKenzie, Rubin, Miller & Lybrand, LLP
Post Office Box 58
Columbia, SC 29202

REFERENCE: Jill Demark v. Jetson Electric Bikes, LLC and Amazon.com, Inc.
C/A No.: 9:20-cv-3706-MBS
Date of Loss: September 26, 2017
CORE File Number: 3-7275-4671

Dear Mr. McKenzie:

Per your request, CORE Engineering has completed its engineering analysis of a fire that damaged rental property owned by Jill Demark. The property's address was 66 Mroz Road, Beaufort, South Carolina. The purpose of the engineering analysis was to determine the origin and cause of the fire. This report contains CORE's present findings and opinions. If necessary, CORE will supplement its report to the extent that additional relevant information becomes available.

CORE's engineering analysis of the fire was conducted in accordance with *NFPA 921, Guide for Fire and Explosion Investigations, 2017 and 2021 Editions.*

References used included but were not limited to:

1. NFPA 921, *Guide for Fire and Explosion Investigations*, *2017 and 2021 Editions*
2. Dr. John DeHaan, Dr. David Icove and Mr. Gerald Haynes, *Kirk's Fire Investigation, 8th Edition*
3. Dr. Vyto Babrauskas, *Ignition Handbook*

A list of the reviewed materials is contained in the appendix. The appendix also contains selected photographs, the writer's curriculum vitae, a list of publications for the last 10 years, a list of trial and deposition testimony for the last four years and CORE's current fee schedule.

CORE relied on the above as well as the writer's education, training, experience, and information from or firsthand observations of the fire scene and laboratory examinations to formulate opinions in this matter.

SCOPE OF INVESTIGATION: On October 2, 2017, Brian Yarborough of State Farm Insurance contacted CORE and requested an origin and cause investigation. CORE performed limited scene processing and recovered some fire artifacts on October 3, 2017. We met with Battalion Chief (BC) Grabenbauer of the Burton Fire District at the site. He provided an overview of suppression operations and his investigative findings. CORE interviewed Kathy Brown, the tenant, by telephone. She detailed the events surrounding the fire.

CORE processed the fire scene on December 22, 2017 with other interested parties. As agreed to with the other interested parties, CORE recovered fire artifacts and brought them to our laboratory for further analysis. On April 18, 2018, CORE examined the artifacts at our laboratory with other interested parties.

On September 24, 2019, CORE transferred selected fire artifacts, which consisted of the remains of lithium ion cells from a battery pack to Mack Nance of SAFE Labs, Sanford,

North Carolina. CORE asked Mike Eskra of Eskra Technical Products, Inc. (ETP) to assist with the evaluation of the lithium ion cells. Mr. Eskra coordinated with Mr. Nance to obtain nondestructive x-ray and CT images of selected lithium ion cells with a Nikon XT H 225 ST MicroCT. Mr. Eskra also visually examined the lithium ion cells at SAFE Labs. ETP's report is included in the appendix.

Another interested party examined the lithium ion cells and the x-ray and CT images at SAFE Labs on April 1, 2021. The other interested party surveyed some of the remaining fire artifacts with CORE at our laboratory on April 2, 2021.

During our investigation, CORE examined and disassembled three self-balancing scooters (hoverboards). We functionally tested two hoverboards. One of the tested hoverboards was a Jetson product that was compliant with UL-2272, the Standard for Electrical Systems for Personal E-Mobility. The other tested hoverboard was a Glyro hoverboard (exemplar Glyro hoverboard) that was not compliant with UL-2272. The exemplar Glyro hoverboard was substantially similar to the subject Glyro hoverboard that was in the room of origin at the time of the fire.

DESCRIPTION OF STRUCTURE: The home was a one-story, wood-frame structure built around 2004. It was in a residential neighborhood in plain view of the surrounding homes. We will refer to the front of the home as South.

The south entrance door opened into the living room in the middle of the home's south side. The dining room was on the north side of the living room. The kitchen adjoined the dining room's west side.

The home had three bedrooms. The master bedroom suite was on the west side of the living room. A short east/west hallway on the east side of the living room led to two bedrooms and a hall bathroom on the east end of the house. We will refer to the northeast bedroom as Bedroom 1.

A full size bed was on Bedroom 1's north side. The headboard was adjacent to the west wall. A dresser was near the foot of the bed along the east wall. A flat screen television was on a small stand against the south wall near the door.

UTILITY SERVICE: At the time of the fire, SCE&G provided electric service to the house. An underground service lateral was routed to the meter base on the home's east exterior wall. A feeder ran from the meter base across Bedroom 1's ceiling cavity to the 200-amp Square D panelboard on Bedroom 1's west wall just inside the door. The panelboard fed 18 branch circuit cables. Two branch circuit cables were bottom-fed from the panelboard. The rest of the branch circuit cables and the feeder were top-fed. The aluminum feeders melted above the main circuit breaker from exposure to the fire's high temperatures. CORE found all the circuit breakers in the tripped position. Environmental heat from the fire probably caused most of the circuit breaker trips.

BACKGROUND: Ms. Denmark purchased the home for use as a rental property in 2007. Ms. Brown moved into the house in 2015. She lived in the house with her two children. None of the home's occupants smoked cigarettes.

Ms. Brown had no electrical problems in the home. The tenant said that all of the home's electrical system's duplex receptacles, switches and fixtures were functional. Since Ms. Brown had lived in the house, she did not report any lightning damage to the home or any of its equipment. The tenant did not have any rodent issues in the home's attic or living space.

On December 21, 2015, Ms. Brown purchased a Jetson Electric Glyro Self Balancing Scooter (subject Glyro hoverboard) from Amazon.com LLC. She bought the hoverboard for her son. Ms. Brown told CORE that they had no problems with the hoverboard. They had not made any repairs to the hoverboard. The hoverboard's battery pack and battery charger were reportedly original. A screen shot of the hoverboard's purchase receipt that was provided by Ms. Brown is shown in Figure 1.

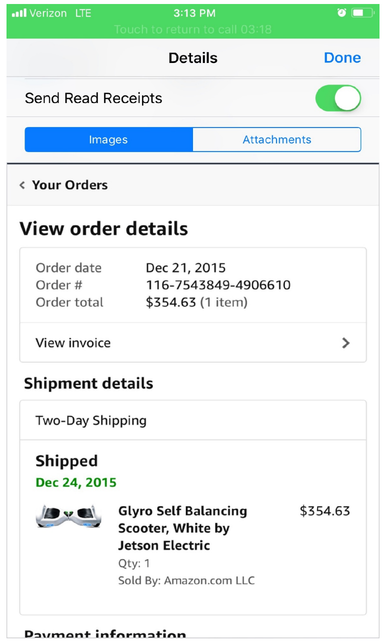


Figure 1 - Product Receipt

Ms. Brown's son reportedly used the hoverboard frequently when it was first purchased. After he got his driver's license, Ms. Brown said her son used the hoverboard less often. Before the day of the fire, she said the hoverboard was last charged around August 2017.

EVENTS SURROUNDING THE FIRE: On the night of the fire, Ms. Brown and her children were in the house. She told her 16-year-old son to clean up his room so she could get the carpets shampooed. Her son plugged the hoverboard's battery charger's 120-volt power cord into Bedroom 1's west wall's duplex receptacle. He connected the battery charger's output cord to the hoverboard that was near the west wall just under the south side of the bed.

The son went to the hall bathroom and took a shower. While her son was taking a shower, Ms. Brown was in the kitchen about 20 feet from Bedroom 1. About 45 minutes after her son began charging the hoverboard, Ms. Brown heard a "whoosh" sound. She went from the kitchen to the hallway and looked into Bedroom 1, seeing flames at the hoverboard under the bed. Because of the bed, the tenant was unable to smother the fire at the hoverboard. Ms. Brown went back to the kitchen to get water. By the time she returned

to the bedroom, the fire was too advanced to be extinguished with the available means. Ms. Brown and her children egressed from the house. Ms. Brown told CORE that no one was injured as a result of the fire.

The fire department received the alarm at 11:41 p.m. On arrival at 11:47 p.m., firefighters saw flames extending from Bedroom 1's east and north windows. They suppressed the fire in Bedroom 1.

BC Grabenbauer inspected Bedroom 1. Fire officials found some remains of the hoverboard and its battery pack's lithium ion cells, placing them near the east window. They put other artifacts from the bedroom's debris field in the east yard.

ORIGIN AND CAUSE DETERMINATION:

Origin Determination - To determine the fire origin area, CORE relied on witness observations, fire effects and fire dynamics as delineated in NFPA 921, Chapter 18, 2021 Edition. The accounts of fire officials, the ventilation patterns from Bedroom 1's east and north windows and the fire extension patterns from Bedroom 1's doorway into the hallway supported Bedroom 1 as the room of origin. CORE and other interested parties systematically removed the debris from Bedroom 1 and reconstructed its furniture pieces. Based on the fire patterns on the east wall's dresser and consumption patterns on the south side of the bed's wood frame, CORE rejected origin hypotheses in the bedroom's northwest quadrant, northeast quadrant and southeast quadrant. The burn patterns and fire dynamics were consistent with an origin area in Bedroom 1's southwest quadrant.

CORE then evaluated Ms. Brown's witness account of the fire to assess our working hypothesis that the fire originated in Bedroom 1's southwest quadrant. Ms. Brown's description of the fire, which was obtained independently by BC Grabenbauer and CORE, validated our working hypothesis that the fire originated in Bedroom 1's southwest quadrant. As detailed in NFPA 921 Section 18.8.3 Eyewitness Evidence of Origin Area, CORE utilized Ms. Brown's observations to conclude that the fire originated in Bedroom 1 at or near the hoverboard that was just under the south side of the bed.

Fire Cause Determination - NFPA 921 defines fire cause as the circumstances, conditions or agencies that bring together a fuel, ignition source and oxidizer (in this case air or oxygen) resulting in a fire.

CORE considered the possibility that the fire was incendiary. We did not find any NFPA 921, Chapter 23 incendiary indicators at the fire scene.

Plausible accidental ignition scenarios in and around the origin area included the following:

1. Heat energy from a failure of the home's electrical system that ignited building materials or common combustibles.
2. Heat energy from a failure of the hoverboard's battery charger that ignited nearby combustibles, like the bed or bedding.
3. Heat energy from a failure of the hoverboard that ignited internal components and/or nearby combustibles, like the bed or bedding.

CORE surveyed the home's electrical system to establish if a prefire failure in the electrical system ignited the fire. We inspected the Square D panelboard that was in Bedroom 1. CORE traced and examined the exposed branch circuit cables, receptacles and switches in Bedroom 1. Circuit breaker #21, an arc fault circuit interrupter circuit breaker (AFCI), protected Bedroom 1's duplex receptacles. A normally functioning AFCI circuit breaker analyzes arcing conditions on the circuit and may provide enhanced protection from fires. From our site inspections and laboratory examination of the artifacts, CORE found no evidence that a failure in the home's electrical system contributed to the fire's ignition.

CORE then considered a failure of the hoverboard's battery charger as the fire's ignition source. The battery charger's 120-volt AC input power cord connected to one side of the battery charger. The battery charger for the exemplar Glyro hoverboard contained a rectifier and other components on a printed circuit board (PCB) that converted 120-volts AC to 42-volt DC. The 42-volt DC output cord connected to the hoverboard's three-pin keyed male charging port to charge the product's internal battery pack. CORE believes

the basic components and overall operation of the subject Glyro hoverboard's battery charger was substantially similar to the exemplar Glyro hoverboard's battery charger.

As stated above and shown in Figure 2, Ms. Brown said the hoverboard's battery charger was the original charger for the subject Glyro hoverboard.

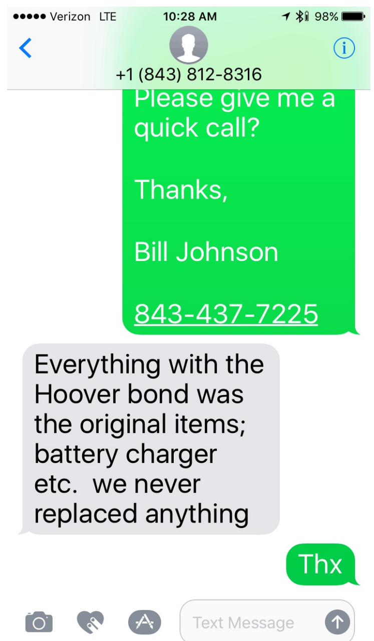


Figure 2 - Screen Capture of Ms. Brown's Text to CORE on March 3, 2018

On October 3, 2017 during CORE's limited scene processing, we recovered some artifacts and loose debris from in and around the hoverboard's prefire location. The loose debris was searched and sifted at CORE with other interested parties. An artifact in that debris was similar in size and shape with a typical battery charger's PCB. Most of the components, like the transformer, diodes, capacitors and resistors were missing from the PCB. Various loose components and cord fragments were discovered during the sifting of debris from the bedroom's west side. Heat from the fire may have melted the solder at the PCB's eyelets, allowing the components to detach. Due to the condition of the PCB, the array of loose components and cord fragments, CORE cannot rule out a failure of the battery charger or its power cord as the fire's ignition source.

Lastly, CORE evaluated a failure of the hoverboard as the fire's ignition source. Figures 3 and 4 show the nomenclature for the components of a typical hoverboard, like the subject Glyro hoverboard.

Figure 3 - Hoverboard External Component Nomenclature

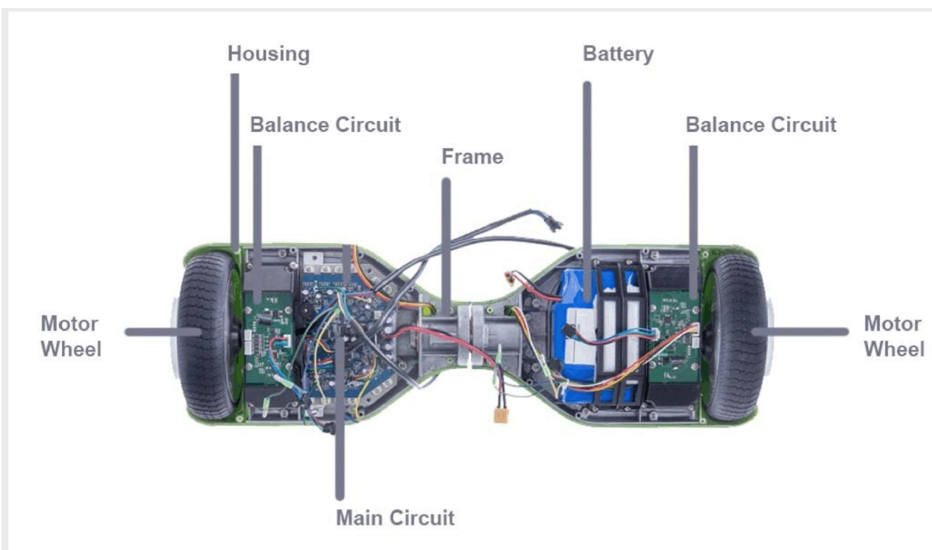


Figure 4 - Hoverboard Internal Component Nomenclature

A hoverboard's aluminum alloy frame consists of two solid pieces with a pivot joint in the middle. The pivot joint allows each side to independently rotate about 40 degrees. As shown in Figure 4, the battery pack and one balance circuit board are on one side (battery

side) of the hoverboard. The main circuit board and the other balance circuit board are on the opposite side.

CORE inspected the remains of the subject hoverboard. The fire consumed the hoverboard's plastic shell. CORE found localized melting and mass loss of the aluminum frame under the location of the battery pack that caused the frame to separate. The localized melting of the frame shows that temperatures around the battery pack exceeded around 1,200°F, the typical melting temperature for aluminum alloys. CORE examined, photographed and obtained radiographic images of both motor wheels, the main circuit board, its adjacent balance circuit board and the remaining conductors. Those components were still attached to the hoverboard's frame. We also surveyed the other balance circuit board, which was recovered from the debris field, using the same procedure as above. The main circuit board, both balance circuit boards and the remaining conductors had varying degrees of environmental heat damage. CORE found the remains of carpet materials on the bottom of the hoverboard frame, supporting Ms. Brown's account that the hoverboard was on the floor at the time of the fire.

The subject hoverboard's 36-volt battery pack consisted of twenty 18650 lithium ion cells and the battery management system BMS module. Literature for the Glyro hoverboard states that the lithium ion cells were made by Samsung. The battery pack's lithium cells separated from the battery pack during the fire. Some of the cells were found in or near the hoverboard remains by fire officials. CORE found other cells during the joint scene processing and subsequent laboratory examination. A total of 18 lithium ion cells and the BMS module were recovered. The BMS module's conductors, which were interconnected to the lithium ion cells were separated from the module and displaced in the debris field. The BMS module from the subject hoverboard's battery pack was substantially similar to the BMS module from the exemplar Glyro hoverboard's 36-volt battery pack, which was labeled "NNC LI-ION SAMSUNG 22P."

CORE tested the charging function of the exemplar Glyro hoverboard. The battery charger port was next to the hoverboard's power switch. When we connected the energized battery charger's output cord to the subject Glyro hoverboard, 42 volts DC was routed to

the main circuit board. Two conductors ran from the same area of the main circuit board through the pivot joint “tunnel” between the two sides of the hoverboard to the battery pack. They provided 42 volts DC to charge the battery pack. CORE saw no evidence of localized damage or a prefire failure to the subject main circuit board or the remains of the charging conductors connected to it.

As stated above, CORE found localized melting and mass loss to the hoverboard’s frame under the battery pack. Since the hoverboard was at floor level where temperatures during a compartment fire are typically lower than at other levels of the room and the damage was localized, the damage to the hoverboard frame was consistent with damage caused by heat energy from a lithium ion cell(s) failure. CORE asked ETP to evaluate the lithium ion cells to determine if the lithium ion cells failed due to fire attack or a prefire failure. ETP’s report is included in the appendix.

Based on the above using the methodology detailed in NFPA 921, CORE has the following opinions:

1. The fire originated in Bedroom 1 at or near the Glyro hoverboard that was just under the south side of the bed.

2. CORE found no evidence that the fire was incendiary.

3. CORE found no evidence that the fire was ignited by a failure of the home’s electrical system.

4. CORE cannot rule out a failure of the hoverboard’s original charger or its power cord as the fire’s ignition source. In some circumstances, heat energy from a failure of the original charger or its power cord could ignite the nearby bed or bedding.

5. CORE saw no evidence of a prefire failure in or around the hoverboard’s main circuit board or the remains of the charging conductors connected to it.

6. CORE believes the damage to the hoverboard frame was caused by heat energy from a lithium ion cell(s) failure. Heat energy from a lithium ion cell failure can be a competent ignition source and ignite nearby combustibles, like the bed or bedding. CORE asked ETP to evaluate the lithium ion cells to determine if the lithium ion cell(s) failed due to external fire attack or a prefire failure. ETP's report, which concluded that the cause of the fire was related to an internal short in a lithium ion cell, is included in the appendix.

Opinions and conclusions expressed herein are solely those of CORE Engineering. CORE's findings and opinions are held to a reasonable degree of engineering certainty and are based on information available at the time this report was issued. Should additional information become known, these findings and opinions are subject to change.

Respectfully Submitted,

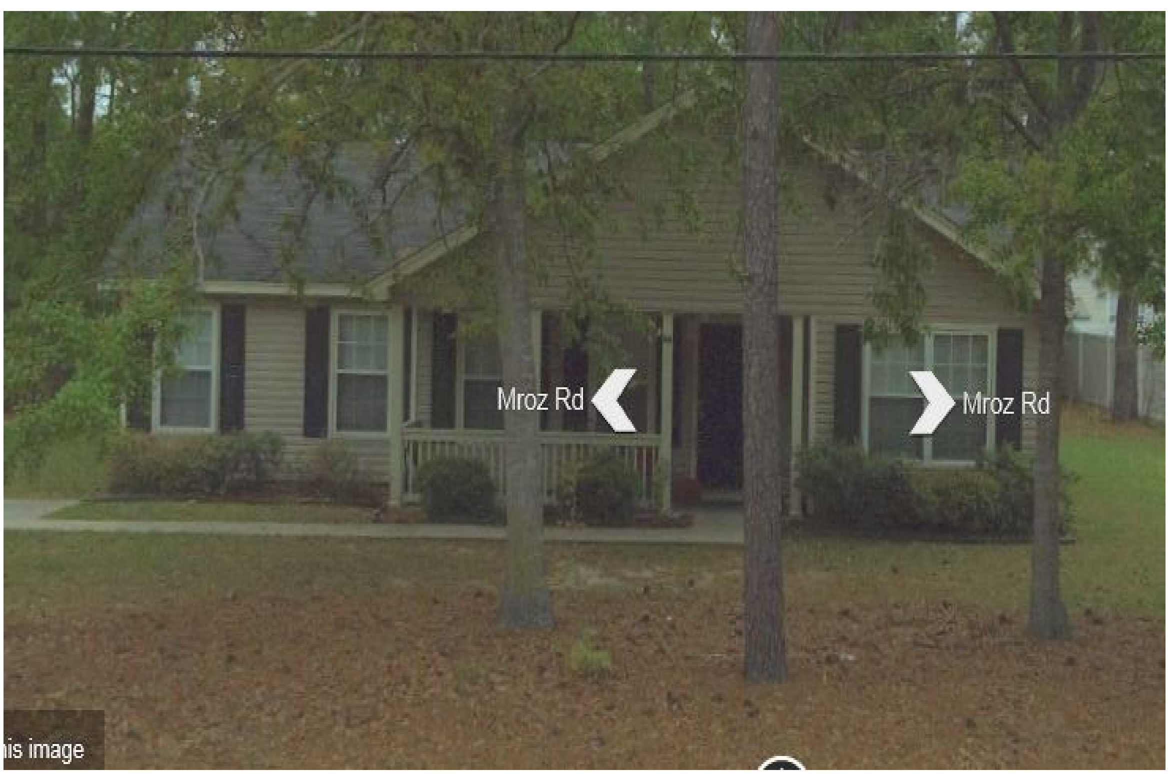
WBJ

William B. Johnson, P.E.
President, CORE Engineering, Corp.

APPENDIX

- Photographs 1 through 28
- Fire Department Incident Report
- ETP Report
- Reviewed Materials List
- Johnson CV
- Johnson Trial and Deposition Summary

Photographs 1 & 2. Prefire Bing images of the neighborhood and the house are shown here. We will refer to the front of the home as South.



Photographs 3 & 4. A prefire Bing image of the house is shown above. The fire originated in Bedroom 1, arrow and below, in the home's northeast quadrant.

Photographs 5 & 6. Views of the home's northeast quadrant are shown here. The fire vented from Bedroom 1's east and north windows.

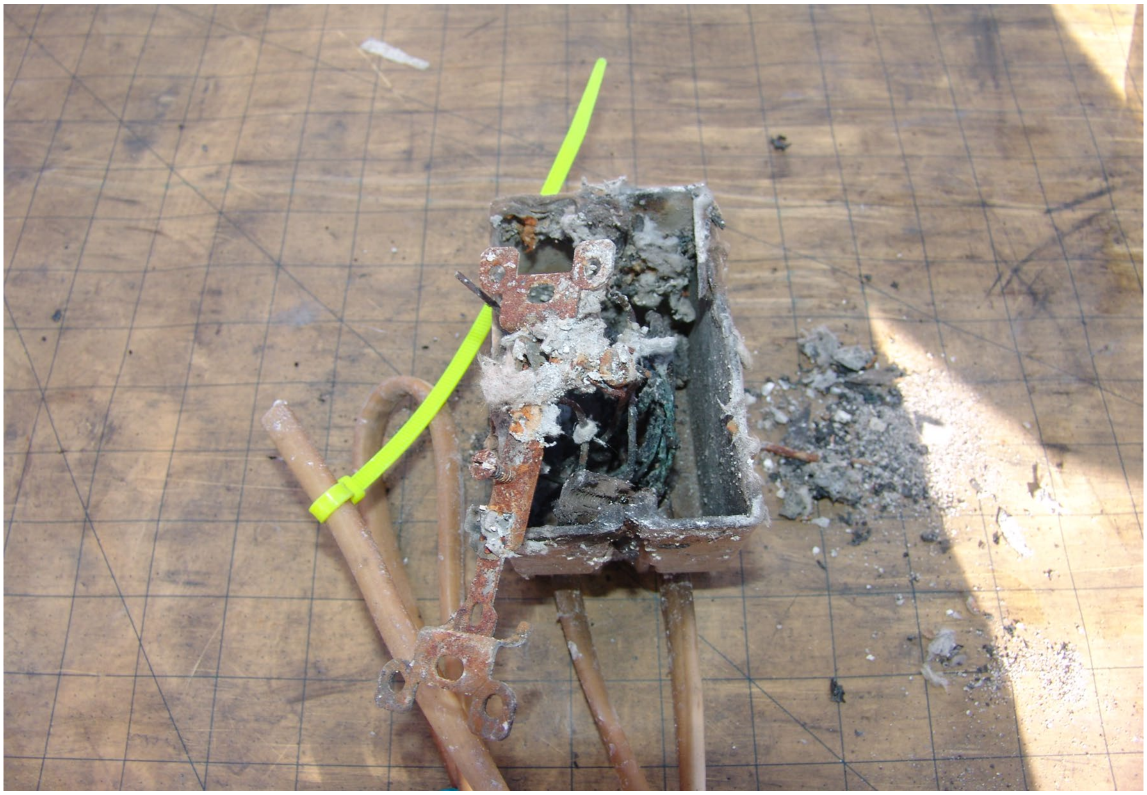
Photographs 7 & 8. A hallway, arrow, on the east side of the living room led to two bedrooms and the hall bathroom. The fire extended from Bedroom 1 into the hallway.

Photographs 9 & 10. Views of Bedroom 1 before scene processing are shown here.

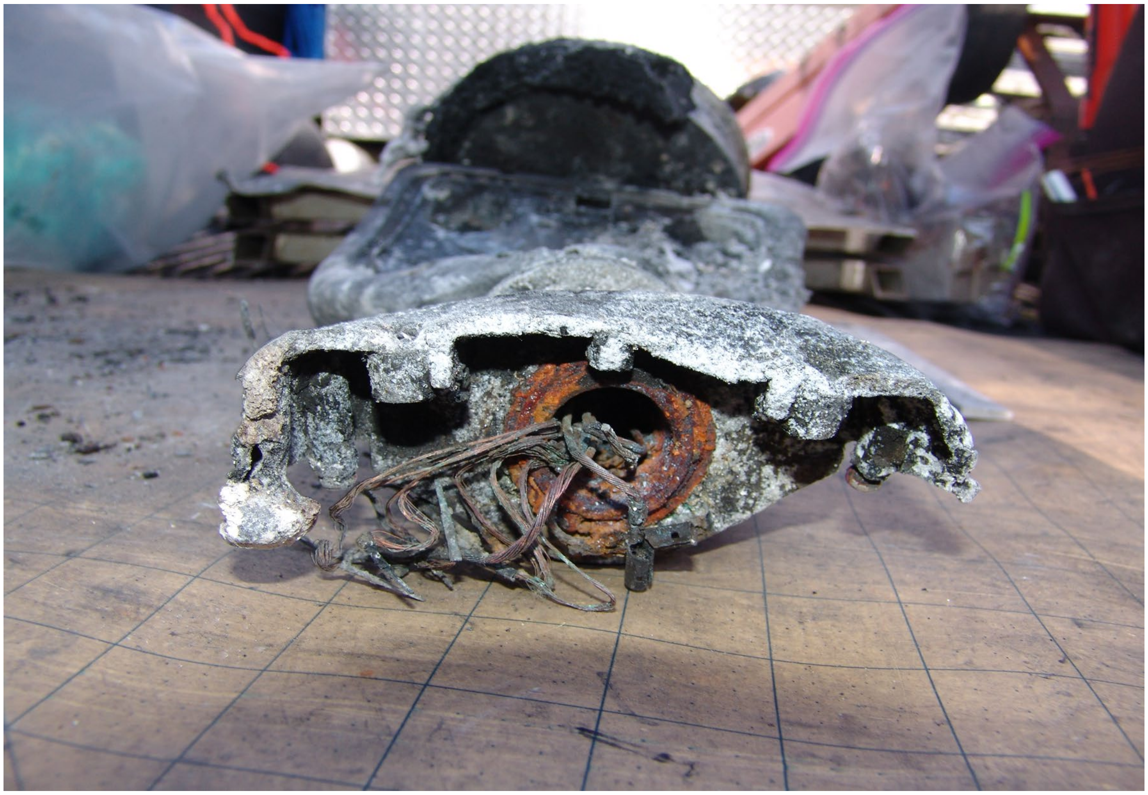
Photographs 11 & 12. Views of the bedroom after processing and debris removal are shown here. A section of the wooden bed frame, red rectangle, was consumed by the fire. The hoverboard was under the bed near the consumed framing.

Case23CV118 PL EX. 243B-019

Photographs 13 & 14. Views of the west side of the room are shown here. The Square D panelboard, arrow, was in the west wall.

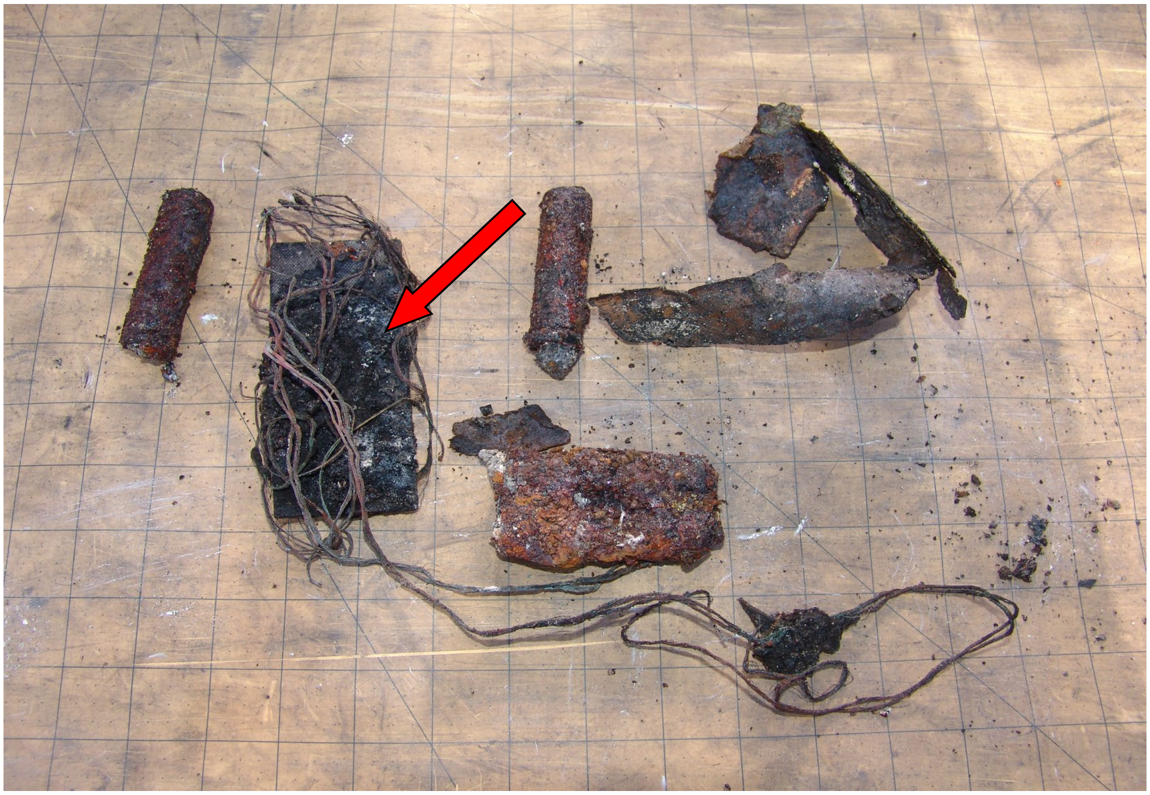


Photographs 15 & 16. The west wall's duplex receptacle's outlet box and segments of its branch circuit conductors are shown above. CORE found the remains of the hoverboard in two sections, below. Carpet remains were adhered to the underside of one of the sections.

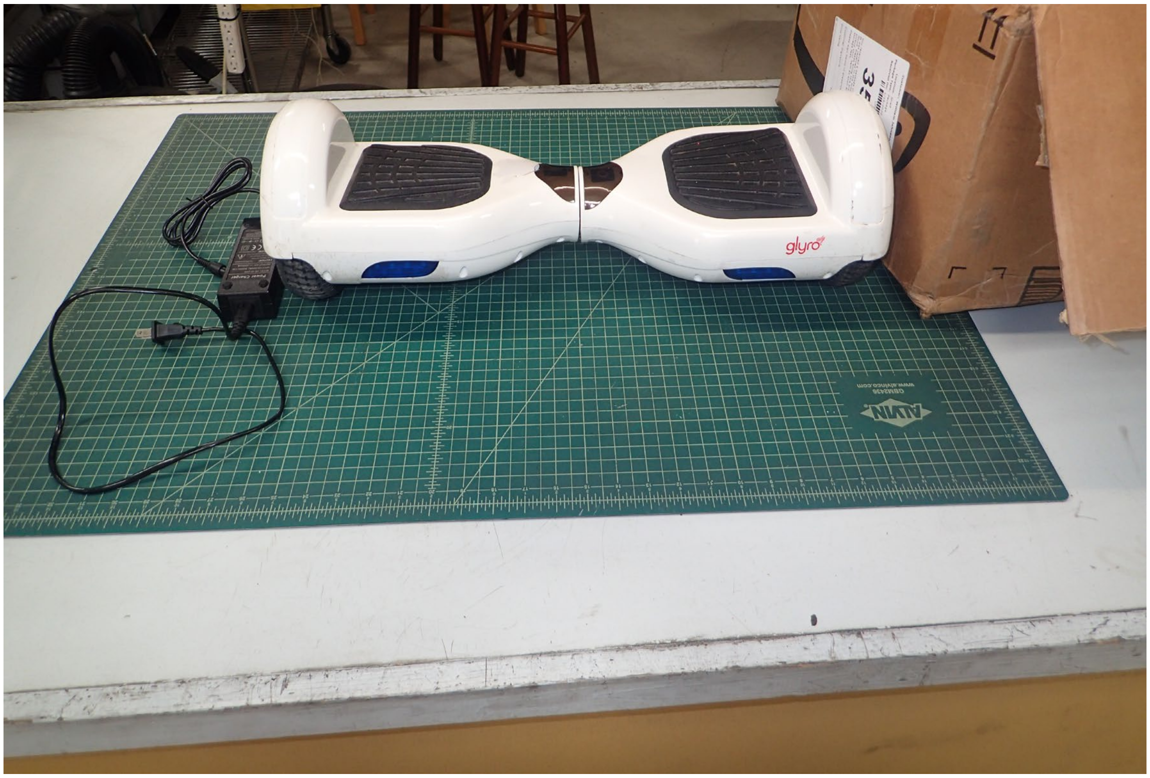


Photographs 17 & 18. Views of the remains of the hoverboard and its conductors are shown here.

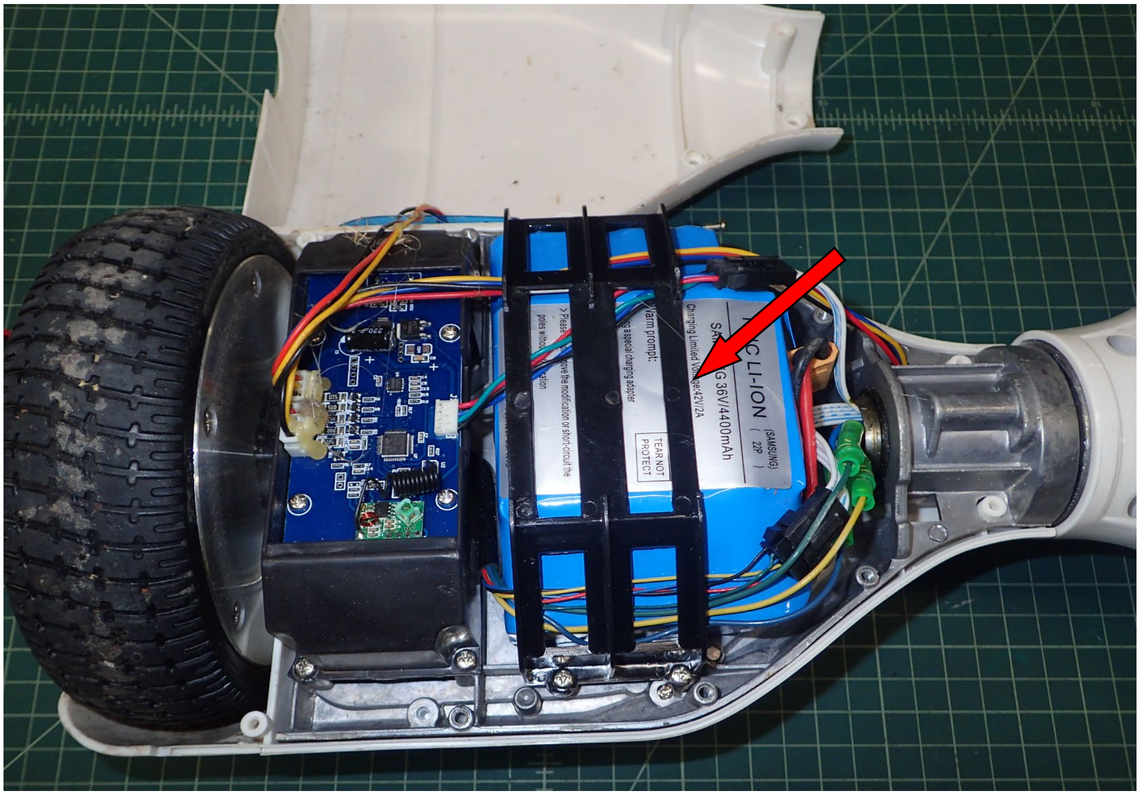
Photographs 19 & 20. CORE found several 18650 lithium ion cells from the hoverboard's battery pack at the site.



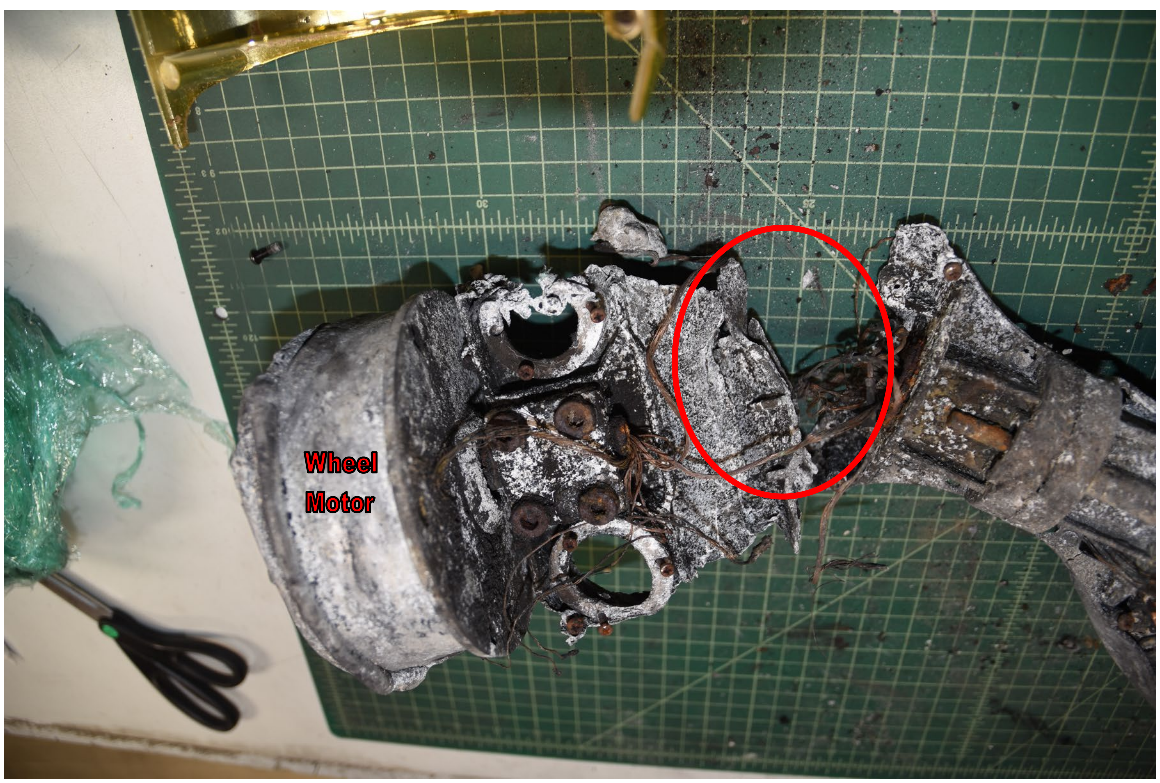
Photographs 21 & 22. Additional artifacts found around the prefire location of the hoverboard are shown above. One of the hoverboard's balance circuit boards, arrow, that was installed next to the battery pack was displaced in the debris field. The remains of a heavily damaged PCB that was similar in size and shape to a typical battery charger's PCB is shown below.



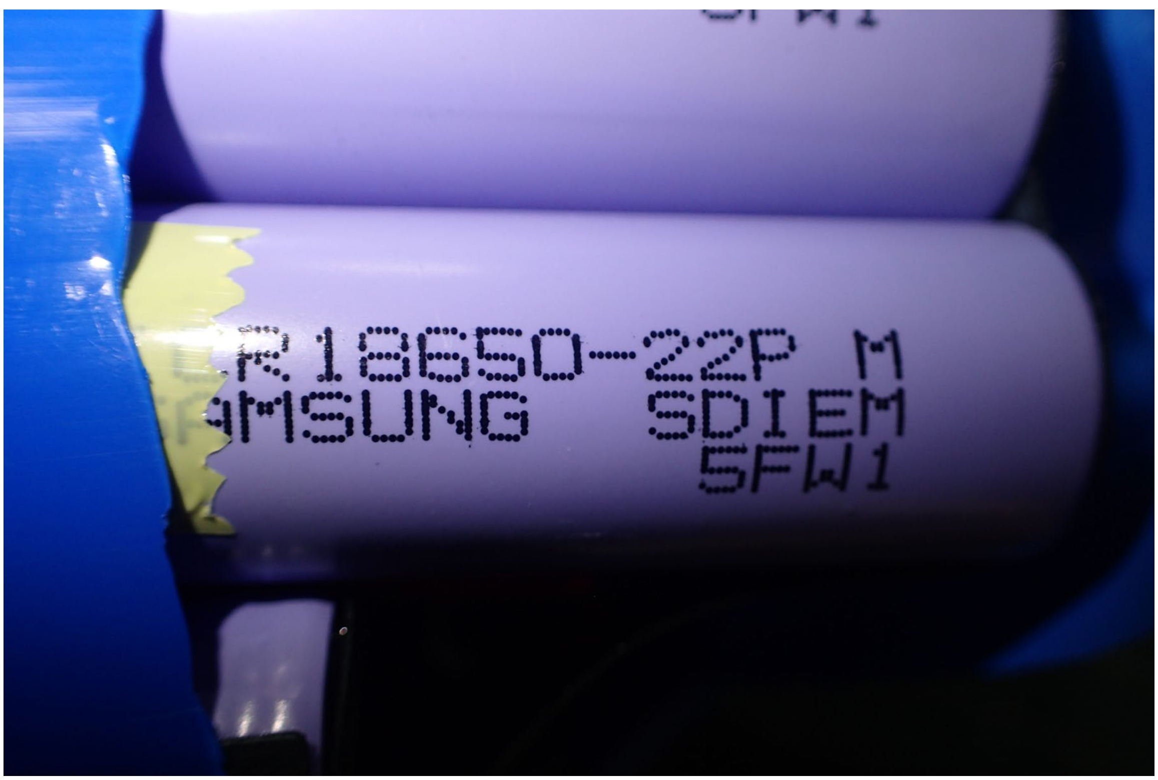
Photographs 23 & 24. CORE obtained, examined and tested an exemplar Glyro hoverboard.



Photographs 25 & 26. The exemplar Glyro hoverboard's battery pack, the balance circuit board that was next to it and a wheel motor are shown above. Below, the subject Glyro hoverboard's frame had localized damage and mass loss, ellipse, around the battery pack's prefire location. The balance circuit board was also displaced, see Photograph 21.



Photographs 27 & 28. The exemplar Glyro hoverboard's battery pack and the markings on some of its 18650 lithium ion cells are shown above and below, respectively.



Burton Fire District
Station: **84**
Shifts Or Platoon: **2**

Location: **66 Morz RD Beaufort (County) SC 29906**	Incident Type: **111 - Building fire**
Lat/Long: **N 32° 27' 33.21" W 80° 46' 40.83"**	FDID: **07303** Incident #: **2017-2695** Exposure ID: **27424244** Exposure #: **0** Incident Date: **09/26/2017**
Zone: **PW1 - Pinewood (County)** Location Type: **1 - Street address**	

Report Completed by:	Baird , Mark	**ID:** 570	**Date:** 09/27/2017
Report Reviewed by:	Grabenbauer , David A	**ID:** 311	**Date:** 10/03/2017
Report Printed by:	Grabenbauer, David A	**ID:** 311	**Date:** 10/3/2017 **Time:** 11:28

Structure Type: **Enclosed building** | Property Use: **419 - 1 or 2 family dwelling**

Automatic Extinguishment System Present: ☐ | Detectors Present: ☑ | Cause of Ignition: **Unintentional**

Aid Given or Received: **Automatic aid received** | Primary action taken: **11 - Extinguishment by fire service personnel**

Additional actions: **81 - Incident command , -**

Losses	**Pre-Incident Values**				
Property:	Property:	Civilian Injuries:	**0**	Fire Service Injuries:	**0**
Contents:	Contents:	Civilian Fatalities:	**0**	Fire Service Fatalities:	**0**
Total:	Total:	Total Casualties:	**0**	Total Fire Service Casualties:	**0**

Total # of apparatus on call: **6** Total # of personnel on call: **14**

NARRATIVE (1)

Narrative Title: 66 Morz Rd.

Narrative Author: Haskett, Mark

Narrative Date: 09/27/2017 11:45:52

Narrative Apparatus ID: E84

Narrative:

Engine 84 responded to a report of a structure fire at the named address. Upon our arrival we found a single family dwelling approximately 15% involved with flames coming out of a window on the D-C corner of the structure. I (FF Haskett) advised dispatch that we had a working structure fire and that all unit would be operating on Ops 1. I then placed the engine into pump and Pulled a 1 ¾ line to the front door and returned to the engine to begin setting up to pump the truck. Vol. FF Rountree arrived and ask me what needed to be done, I then advised him to don a SCBA and get on a team with FF Farris to begin a fire attack through the front door. I then was advised by FF Farris that he was ready for me to charge the attack line, which I charged.

At this time, Engine 85 had arrived on scene and had dropped a 5" supply line to reverse lay to the hydrant. Once Engine 85 had sufficiently pulled away I hooked the 5" line to the truck and when the hydrant was charged, transferred from onboard water to the hydrant water and advised command that a water supply had been established.

A second 1 ¾ "line was pulled and charged for exterior operations at the D-C corner.

NARRATIVE (2)

Narrative Title: 66 Mroz Rd

Narrative Author: Webb, Ethan

Narrative Date: 09/27/2017 11:55:53

Narrative Apparatus ID: E81

Narrative:

Engine 81 arrived on scene and was given the assignment to establish Division 1. Team 81 made entry with a charged 1 3/4" hose line. Lieutenant Webb established Division 1, while Engineer Chapman and Firefighter Nicotri performed Primary Search.

Division 1 consisted of 4 teams, Team 81 was performing Primary Search, Team 84 was performing Fire Attack, Team 89 was pulling ceilings to check for fire in the attic, and Team 85 was assisting with checking for extension.

Team 89 opened the ceiling and didn't find any signs of fire in the attic other than the area of origin. Once the fire was extinguished, Team 81 was able to complete a Primary Search of the structure and gave an "all clear" report. Team 89 exited the structure and reported to command for their next assignment. Team 84 exited the structure once the fire was extinguished. Team

81 and Team 85 remained inside checking for hot spots and ensuring there was no extension into the attic.

After extinguishing all hot spots, crews used an attic ladder to gain access to the attic to check for fire extension. Once in the attic, crews found no signs of fire.

Division 1 gave an "all clear" report and requested Ventilation. A positive pressure fan was setup at the front door to ventilate the structure. Team 85 and Team 81 exited the structure and reported to Rehab.

Engine 81 cleared Rehab and began disconnecting the LDH and reloading it onto Engine 85. Once all LDH was reloaded, Engine 81 was given the assignment to do one final sweep with a thermal imaging camera to check for any residual heat. While sweeping the structure, Lieutenant Webb found some residual heat in the area of origin. Firefighter Farris and Firefighter Nicotri began separating the content and removing the content, which was showing high signs of heat. Once all content that was showing signs of heat were removed, Engine 81 assisted the tenant with removing some of her personal items.

Engine 81 was released from the scene; Engine 81 cleared the scene and returned to

service.

NARRATIVE (3)

Narrative Title: 66 Mroz Road

Narrative Author: Farris, Matthew

Narrative Date: 09/27/2017 11:42:14

Narrative Apparatus ID: E84

Narrative:

I (FF Farris) arrived on scene to a structure fire at the above stated address in the Officers Seat of the first due engine. Upon arrival I began a *360 and found heavy fire showing out two windows of a bedroom on the Charlie Delta corner of the home and working up into the attic above this bedroom. Upon reaching the Alpha Bravo Corner of the home I saw two cars in the driveway and reported these findings to the incoming units. When I reached the front door it was open but at this point still had no confirmation on location of occupants. At this time I called for the second arriving engines Jump FF to meet me at the front door to make entry. The Beaufort County Sheriffs were approximately 100yds down in a neighbor's yard speaking to someone but it was unknown to me if they were the occupants. With the noise of the incoming engines I was not able to yell to them to get a report and decided the time it would take to walk over there was not worth the risk of the fire spreading to more of the house. While donning the rest of my PPE from outside the front door I looked and yelled inside to listen for the response of any victims. After calling for water I bled the hose and adjusted for the correct nozzle pattern. From the front door I began to knock the fire down that was beginning to move out of the bedroom and down the hallway towards the living room. I was joined by Volunteer Rountree and upon arrival of Burton Engine 85 and Engine 89
from MCAS Volunteer Rountree and I made entry into the house and worked our way to the bedroom extinguishing the fire and performing an initial search of the immediate area. Once the fire was extinguished we handed the attack line off to the search team and exited the structure and reported to command. After rehab I assisted in overhaul of the main fire room, gathered information, and assisted in cleanup.

NARRATIVE (4)

Narrative Title: 66 Mroz Rd

Narrative Author: Murray, Hugh

Narrative Date: 09/27/2017 11:49:44

Narrative Apparatus ID: E82

Narrative:

Engine 82 arrived at listed address and assumed RIC for the incident. A 360 was conducted of the structure and "C" side was opened to provide for access. Lighting was provided on "A" and "C" side. Power was secured and water was secured by Engine 82's crew.

Upon securing firefighting operations Engine 82's crew was assigned to overhaul. Engine 82's crew entered the building provided air monitoring and checked for hot spots. Engine 82's crew was instructed to check the bedroom in the "C" and "D" corner for a fire source. An outlet was located with no damage to the wiring where a Hover Board had been plugged in charging. The remnants of the Hover Board was found under where the bed was placed prior to the fire. Hover Board was found in 3 parts, left, right and batteries. As an estimated 45% of the Hover Board was missing from the center. Item was placed in the window for inspection by 804.

Engine 82 returned to service.

NARRATIVE (5)

Narrative Title: 66 Mroz road

Narrative Author: Baird, Mark

Narrative Date: 09/27/2017 12:00:56

Narrative Apparatus ID: E85

Narrative:

Engine 85 was en route to the structure fire at 66 Mroz Road. Command called for a Jump-man from Engine 85 to assist with Fire Attack. Upon arrival Firefighter Baird proceeded to the structure to join Firefighter Farris on fire attack. Engineer Wright dropped supply hose at Engine 84 and reverse laid to the hydrant at the entrance to the Irongate Subdivision. Upon securing the hydrant and a water source to Engine 84, Engineer Wright abandoned the engine and returned to the structure.

Firefighter Baird followed the hose line into the structure and joined the Fire Attack team which consisted of Firefighter Farris and Volunteer Rountree. Firefighter Baird assisted with Fire Attack and extinguishment. The fire was primarily located in the Charlie-Delta corner. During Fire Attack, Firefighter Baird began Primary Search while Firefighter Farris operated the hose line. Nothing was found in the Alpha-Delta corner room or bathroom. After extinguishment the fire room was

searched and nothing was found. Engineer Wright joined the interior team and began to search for hotspots. Ceiling was pulled to check for extension. After all hotspots were extinguished and entire structure was searched and nothing was found. Firefighter Baird and Engineer Wright exited the structure.

Equipment was cleaned, air cylinders replaced, and hose was returned to the truck. Engine 85 cleared the scene and returned to service.

NARRATIVE (6)

Narrative Title: 66 Mroz IC

Narrative Author: Grabenbauer, David

Narrative Date: 10/03/2017 11:27:51

Narrative Apparatus ID: BAT81

Narrative:

Battalion 81 arrived on scene to find smoke coming from the charlie/delta corner of the structure. I then initiated command and began a 360 walk around of the building. There was fire damage to the exterior wall on delta. There was also heavy smoke in the attic space that was coming from the gable vents.

- E84 crew had begun fire attack as fire attack group.
- E85 was establishing water supply to E84 for fire attack.
- E82 arrived on scene and established RIC
- E81 arrived on scene and I assigned Lt. Webb of E81 Division 1(D-1). He took his engine company and requested additional resources for overhaul.
- I assigned E89 to report to D-1 with tools required for overhaul.

I received an all clear in a few minutes from D-1, indicating the house was clear of any occupants.

As the crews worked the products of combustion began to diminish. The fire was under control and then extinguished in a short period of time.

Once overhaul was complete to confirm no extension the PPV fan was used to ventilate the structure.

Crews began to exit the structure and report to rehab.

I assigned E82 to monitor the air in the structure, which the the report came back that the environment was safe to enter without SCBA.

We were able to meet with the residents who told us a hover board was plugged in under a bed in the bedroom on the Charlie/Delta corner of the house. She stated she heard a pop in the room and went to investigate where she found fire coming from the floor level in which the hover board was located. She then stated she went to the kitchen to get water in an attempt to extinguish the fire. However when she returned she found the room to be too heavily involved with fire and she and all other occupants exited the house and called 911.

During our investigation of the fire our findings of the fire and its spread throughout matched that of the residents story.

APPARATUS

Unit	E84	**Unit**	E85
Type:	Engine	**Type:**	Engine
Use:	Suppression	**Use:**	Suppression
Response Mode:	Lights and Sirens	**Response Mode:**	Lights and Sirens
# of People	2	**# of People**	2
Alarm	09 /26/2017 23:41:53	**Alarm**	09 /26/2017 23:41:53
Dispatched	09 /26/2017 23:43:04	**Dispatched**	09 /26/2017 23:43:04
Enroute	09 /26/2017 23:44:31	**Enroute**	09 /26/2017 23:46:04
Arrived	09 /26/2017 23:47:30	**Arrived**	09 /26/2017 23:50:00
Cancelled	-- /-- /-- --:--:--	**Cancelled**	-- /-- /-- --:--:--
Cleared Scene	09 /27/2017 01:49:04	**Cleared Scene**	09 /27/2017 01:19:21
In Quarters	-- /-- /-- --:--:--	**In Quarters**	-- /-- /-- --:--:--
In Service	09 /27/2017 01:49:04	**In Service**	09 /27/2017 01:19:21
Unit	BAT81	**Unit**	E81
Type:	Chief officer car	**Type:**	Engine
Use:	Other	**Use:**	Suppression
Response Mode:	Lights and Sirens	**Response Mode:**	Lights and Sirens
# of People	1	**# of People**	3
Alarm	09 /26/2017 23:41:53	**Alarm**	09 /26/2017 23:41:53
Dispatched	09 /26/2017 23:43:04	**Dispatched**	09 /26/2017 23:43:04
Enroute	09 /26/2017 23:46:12	**Enroute**	09 /26/2017 23:45:21
Arrived	09 /26/2017 23:52:53	**Arrived**	09 /26/2017 23:52:55
Cancelled	-- /-- /-- --:--:--	**Cancelled**	-- /-- /-- --:--:--
Cleared Scene	09 /27/2017 01:49:45	**Cleared Scene**	09 /27/2017 01:49:30
In Quarters	-- /-- /-- --:--:--	**In Quarters**	-- /-- /-- --:--:--
In Service	09 /27/2017 01:49:45	**In Service**	09 /27/2017 01:49:30
Unit	E82	**Unit**	804
Type:	Engine	**Type:**	Chief officer car
Use:	Suppression	**Use:**	Other
Response Mode:	Lights and Sirens	**Response Mode:**	Lights and Sirens
# of People	3	**# of People**	1
Alarm	09 /26/2017 23:41:53	**Alarm**	09 /26/2017 23:41:53
Dispatched	09 /26/2017 23:43:04	**Dispatched**	09 /26/2017 23:43:04
Enroute	09 /26/2017 23:48:50	**Enroute**	09 /26/2017 23:51:09
Arrived	09 /26/2017 23:54:05	**Arrived**	09 /27/2017 00:02:45
Cancelled	-- /-- /-- --:--:--	**Cancelled**	-- /-- /-- --:--:--
Cleared Scene	09 /27/2017 01:04:07	**Cleared Scene**	09 /27/2017 01:47:52
In Quarters	-- /-- /-- --:--:--	**In Quarters**	-- /-- /-- --:--:--
In Service	09 /27/2017 01:04:07	**In Service**	09 /27/2017 01:47:52

Number Of People not on apparatus: 2

FIRE

Acres Burned	None or Less Than One	**Acres Burn From Wildland Form**	False
Area Of Fire Origin	Bedroom - < 5 persons; included are jail or prison	**Heat Source**	Radiated or conducted heat from operating equipment
Item First Ignited	Toy, game	**Fire Is Confined To Object Of Origin**	
Type Of Material	Plastic	**Cause Of Ignition**	Unintentional
Factor Contributing To Ignition	Electrical failure, malfunction, other		
Human Factors Contributing	None		
Equipment Involved In Ignition Flag	True	**Equipment Involved**	Battery charger, rectifier
Equipment Power Source	Electrical line voltage (>= 50 volts)	**Equipment Portability**	Portable

STRUCTURE FIRE			
Structure Type	Enclosed building	**Building Status**	In normal use
# Of Stories At Above Grade	1	**# Of Stories Below Grade**	0
Square Feet	1200	**Length**	
Width		**Floor Of Origin**	1
Fire Spread	Confined to room of origin		
Minor Damage	1	**Significant Damage**	0
Heavy Damage	0	**Extreme Damage**	0
Presence Of Detectors	Present	**Type Of Detection System**	Smoke
Detector Power Supply	Hardwire with battery backup	**Detector Operation**	Detector operated
Detector Effectiveness	Detector alerted occupants, occupants responded	**Detector Failure Reason**	

PEOPLE -- PERSON 1			
Is Owner	False	**Business Name**	843-812-8316
Telephone Number		**Involvement**	Occupant renter
Name	Lakesha Brown	**Date of Birth**	3/23/1983
Address	66 Morz RD Beaufort (County), SC 29906-		

PEOPLE -- PERSON 2			
Is Owner	False	**Business Name**	
Telephone Number		**Involvement**	Occupant
Name	Dominic Dasher	**Date of Birth**	7/13/2001
Address	66 Morz RD Beaufort (County), SC 29906-		

PEOPLE -- PERSON 3			
Is Owner	False	**Business Name**	
Telephone Number		**Involvement**	Occupant
Name	Caylyn Johnson	**Date of Birth**	10/14/2010
Address	66 Morz RD Beaufort (County), SC 29906-		

CUSTOM FIELDS FORM	
Was the call type you found the same as the call type dispatched?	Yes
Residency of the person you provided service to:	Resident of Burton Fire District
If NO, what call type were you dispatched to?	
Did Burton personnel go with the ambulance to the hospital?	NO
If you installed a smoke detector on this call, choose YES. (otherwise skip)	

Member Making Report (Firefighter II Mark Baird): __________

Supervisor (Battalion Chief David A Grabenbauer): __________

ETP
Eskra Technical Products, Inc.

2595 County Rd I Saukville, WI 53080 560 Technology Way STE #7 Saukville, WI 53080
Office/Lab/Shop (262) 235-4068

Jill Demark
v
Jetson Electric Bikes, LLC and Amazon.com, Inc.

Prepared

April 19, 2021

for

Bill Johnson

CORE Engineering

1000 Johnnie Dodds Blvd

Suite 103-357

Mount Pleasant, SC 29464

coreenginc@aol.com

Prepared

By

Mike Eskra,

CFEI, CVFI, CFII 16215-9447

ETP
Eskra Technical Products, Inc.

2595 County Rd I Saukville, WI 53080 560 Technology Way STE #7 Saukville, WI 53080
Office/Lab/Shop (262) 235-4068

1-Assignment

Mike Eskra was asked to review x-rays and CT scans to determine if the cells scanned were the origin of the fire.

2-Scope

Mike Eskra reviewed x rays of the cells recovered from the scene, using the x-rays to select a few of the cells for CT scanning. These scans were reviewed and were used in the preparation of this report.

3-Procedure

Using the guidelines of NFPA 921 along with the scientific method, we reviewed the x-rays and CT scans. Finally, the cells were visually inspected at SAFELAB.

4-Lithium Battery Background

Batteries have unique characteristics of operation which allow them to be used under a wide range of operational conditions. Under normal operation, most users find them to be rather ubiquitous, and embedded in their daily lives. In the determination of whether the cause of an incident is related to a battery, there needs to be a high level of scientific process applied and evaluation of all know facts, artifacts and observations along with procedures outlined in NFPA 921.

Some background on lithium ion cell chemistry, battery construction and pack construction will assist in understanding the balance of our analysis of the battery cells.

Lithium ion batteries, when heated and charged or otherwise abused, may experience a rapid rise in temperature, commonly called a thermal runaway. Thermal runaway can be caused by either an internal short circuit (manufacturing defect, or lithium dendrite formation) and/or overheating of the Li-ion cell (typically from exposure to temperatures above 60° C), over discharging below a specific level, or cold charging of cells that are below or near their freezing point.

When a cell enters thermal runaway its temperature increases rapidly. Depending on the cell's particular chemistry, design and level of charge, a cell in thermal runaway can reach temperatures high enough to allow the aluminum cathode current collector to melt and vent with the electrolyte, and possibly form a thermite cloud and explosion. If thermal runaway occurs in a

Eskra Technical Products, Inc.

2595 County Rd I Saukville, WI 53080 560 Technology Way STE #7 Saukville, WI 53080
Office/Lab/Shop (262) 235-4068

single cell, the thermal management system must be able to absorb the heat of the thermal runaway in order to prevent a fire, explosion or other catastrophic incident.

Typical cylindrical lithium ion cells have several internal safety features built into them as shown in **Figure 1**, below. One device, known as the Positive Temperature Coefficient device (or PTC) which protects the cells under an external shorting condition by increasing its resistance as the cell gets hotter. At a sufficiently high temperature, little or no current should flow through the PTC. Many high power cells, such as used by power tools and other devices do not contain this protective device. As long as proper batter pack management is provided for this will work well. Another device, called the Current Interrupt Device (CID), protects the cells under overcharge conditions. It operates by physically disconnecting the cell from the load if the cell pressure exceeds a certain control limit. At this point, the CID will also serve to vent the gas pressure into the surrounding environment. It is typically seen at a fire that some of the cells have blown apart or appear to be empty shotgun shells. These cells had to develop a very quick increase in pressure that even an opening CID vent could not dissipate the energy quick enough to relieve the building pressure. The secondary venting system is that the crimped end cap expands and is dislodged to vent the cell. Cells will typically vent at 150 to 450 psi.

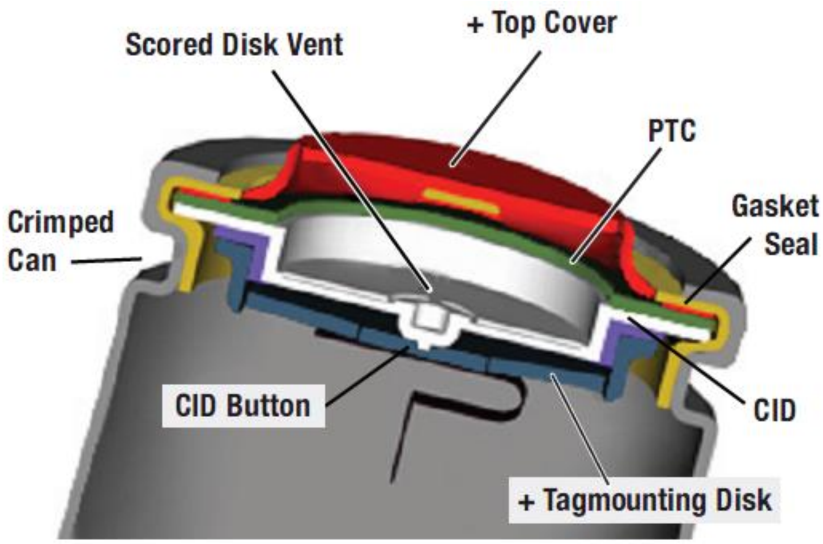


Figure 1. Typical Devices Present Within an 18650 Lithium Ion Cell. (NASA Tech N0.92-02)

ETP
Eskra Technical Products, Inc.

2595 County Rd I Saukville, WI 53080 560 Technology Way STE #7 Saukville, WI 53080
Office/Lab/Shop (262) 235-4068

It is not abnormal for a high-rate device to not have a PTC. It has been found that the presence of the PTC, when used in a high-rate device, will actually cause cells in the battery pack to become unbalanced over normal intended usage.

When building a battery pack, it is important to ensure that the cells used are matched in terms of capacity (best if matched at several rates), and internal impedance. It is also important that the cells are treated similarly throughout life. Exposing cells of a battery pack to unequal external heating or vibration would allow normal failure modes to accelerate the aging process in some cells, causing cell capacity and power separation. It is not uncommon to have cell capacities fade significantly from each other in a battery pack. A proper battery management system is required to identify and prevent damage to a cell from being over discharged or overcharged in all battery chemistries, but most importantly, in lithium ion and lipos.

5-Battery Failure Modes

Any event, which can lead to increased cell pressure, is of concern, since the electrolyte is a mixture of flammable solvents and a toxic salt material. For safe operation of lithium ion cells, it is a requirement that overcharge or over discharge be avoided. Overcharge is that point where the application of additional charging current can lead to degraded cell life, or in more extreme cases, a safety hazard. It manifests itself as a battery voltage on charge, higher than a pre-specified safety limit (typically 4.15 to 4.20 V / cell for most lithium ion consumer cells). Over discharge is typically considered to occur below 3.0 Volts. The operating voltage window of the cell significantly effects cycle life. Where extra-long life is required, operation between 3.9 and 3.2 volts is utilized, this, of course, is at the expense of overall cell capacity. Both the upper charge voltage and lower discharge voltage is dependent upon the particular cells positive to negative active material ratio. The battery cell performance is dependent upon the overall manufacturing quality and consistency of the electrodes, separator, cell component alignment and electrolyte type and quantity. Both overcharge and over discharge create by-products that are not reversible, are irreparable and the damage done is accumulative and does not recombine back into the cell. These by-products significantly increase the possibility of a catastrophic failure.

The electrolyte within the cell is composed of flammable solvents which can also decompose if the cell voltage is sufficiently high. Overcharge can lead to plating of lithium metal on the anode, as can over discharge and subsequent charging, which can lead to the development of metallic

Eskra Technical Products, Inc.

2595 County Rd I Saukville, WI 53080 560 Technology Way STE #7 Saukville, WI 53080
Office/Lab/Shop (262) 235-4068

electrical shorts within the cell, called dendrites, caused by the dissolution of the copper anode current collector. If the short is sufficiently well-developed, it can lead to an extremely fast discharge current within the cell, that protective devices are not able to control. This rapid discharge current will lead to a rapid increase in cell temperature, release of flammable solvents ("venting"), and possibly fire or explosion. With certain cathode materials, overcharge will also cause the release of gaseous oxygen. This combination of flammable solvents, oxygen, and gas pressure can lead to an explosive event. For this reason, the battery management system and/or charger must intercept and shut down a failing battery prior to any significant event occurring.

The decomposition reactions are well documented. For instance, E. Peter Roth and G. Nagasubramanian of Sandia National Laboratories did a detailed thermal degradation study in 1999 on Sony's lithium ion technology, which is the baseline of the industry (Appendix A). The data from this study is still relevant and the decomposition reactions still occur. It should be noted that the data presented in the appendix to this report, was generated in cells which, when compared to today's technology, had low power and energy. The increase in power capability and much higher capacities provide proportional energy during a thermal runaway event.

Accelerated Rate Calorimetry (ARC) studies indicate that the cathode material, cobalt oxide, becomes much more unstable when the battery is at full state of charge. It has a significant lowering of initiation temperature and an increase in overall exothermic energy compared to its state when the battery is nearly discharged.

Discussions with separator manufacturers and developers, relating to the long-term stability of commercial lithium ion separators, in batteries held at full state of charge, tell of degradation via discoloration and cracking, leading to shorting, even though the batteries are not being cycled via charging and discharging. These degradation reactions can also occur in cells used for high-rate applications due to localized high current densities.

Sandia National Laboratories, with cooperation from LG Chem, through its American affiliates, have been studying the effects of internal shorts and the subsequent cell propagation through battery packs under DOE funding. The data shows that many times the secondary reactions of the decomposition products of the shorted cell may be more energetic than the primary reactions.

Eskra Technical Products, Inc.

2595 County Rd I Saukville, WI 53080 560 Technology Way STE #7 Saukville, WI 53080
Office/Lab/Shop (262) 235-4068

These cell failures can occur either through external sources such as overheating through operation, or fire, or can also occur through manufacturing defect or failure due to degradation of materials due to cycling or other aging or abuse factors discussed above.

Lithium ion chemistry has very good efficiency and can have excellent cycle life when operated properly. However, abuse, whether through overcharge, over discharge, external shorting, is accumulative and is not repairable. Damage done early in life remains and further damage will accumulate. Cell failure can occur within a cycle, days, weeks or months later, depending upon the severity of the initial damage and subsequent cell treatment. The minimum effect of abuse is diminished cycle life. The act of charging and discharging can indicate how a particular device or user is treating a battery. For instance, if the voltage of a lithium ion battery is controlled such that a cell only operates between 3.1 to 3.9 volts many tens of thousands of cycles can be achieved, such as batteries used in spacecraft. That same cell operated at 3.0 to 4.2 volts may only provide 800 to 2000 cycles, such as cell phones. If operated from 1.0 to 4.24 Volts, the cell may only provide 40 cycles, such as some hover boards and e-cigarettes.

Lithium electrodes swell and contract on cycling. These expansions and contractions, which occur in all directions but primarily measured in the Z direction, or thickness of the electrode, will cause significant pressures to build up in prismatic cell stacks and cylindrical cells. Typically, this can be seen in jelly rolls of cylindrical cells as the jelly roll will fold unto itself and even rotate in the can as the cycle life accumulates. In all cell designs the electrodes may stretch and cause misalignment issues or compression of the separators enough to make them begin to flow. If contamination exists, such as lumps of active material or external contamination left from shoddy manufacturing practices, these can be pushed through the separator, leading to shorting. These compressive forces are greatest when the cell is being charged above 3.9 to 4.4 volts or discharged below 3.1 volts and below. When a lithium ion cell is discharged to below 2.5 volts substantial shifts in the active material structure also occur, primarily in the cathode. Upon recharge of these lower state of charge batteries there is an increase in the instability of the active materials. Typically, cell manufacturing occurs in a dry, clean, area, limiting the possibility of foreign materials entering the cell assembly area. The electrodes themselves are typically scanned during the coating and assembly process to eliminate foreign contamination. Additional tests are performed after the cells are assembled and formed (first charge). One of the tests normally performed is a 30 to 60 day open circuit stand where the open circuit voltages are monitored. If a cell exhibits a falling voltage over that time, it is rejected from shipment.

Eskra Technical Products, Inc.

2595 County Rd I Saukville, WI 53080 560 Technology Way STE #7 Saukville, WI 53080
Office/Lab/Shop (262) 235-4068

The process to make lithium ion electrodes is continually evolving. The current collectors and coatings are very thin, with current collectors of 12um (0.00055") and coatings of 25 to 80um (0.001 to 0.0035") typically used. Separator thickness is typically 25um (0.001"). Therefore, the cleanliness and uniformity of the surface of the electrodes needs to be carefully monitored to prevent foreign bodies, debris or lumps of active materials to be built into the batteries. These thin layers of electrodes are either wound tightly into cylindrical cells or layered one on top of the other and built into a tight pack. Any sharp components can easily penetrate the polymer separator and lead to a shorted cell. Penetration of the separator, or even separator thinning due to excessive compression and subsequent plastic flow of the separator, by any material, whether conductive or not will decrease the local potential of the cell in that area and lead to overall cell discharge. This is known as a cell's high self-discharge, or soft shorting, where the shorting is ionic. The problem is when the soft shorting evolves into to a hard short. A hard short is electronic and allows high current to pass, usually requiring a large heat flux to be dissipated.

When lithium ion batteries fail, or are driven into failure, distinctive characteristics remain. Analysis of the failed cells can, many times, indicate the failure mode which occurred. The remnants can also provide a reasonable indication of how the battery was treated over its life.

6-Analysis of the Artifacts

X-rays were taken of the cells recovered from the fire and are shown in the following seven figures. Then looking at x-rays of cells involved in a fire it is not unusual for the jelly roll to be partially or completely expelled. At the first cut, the x-ray of the contents and of the remaining steel can components, allow down select of cells for CT scanning to occur. **Figure 2** is an x-ray of cells labeled 3A, 3B and 3C. It is unclear of when this nomenclature was assigned. Cells 3B and 3C are examples of cells that clearly were attacked by fire. The negative ends are rounded and a gas pocket has formed in that rounded end pushing the jelly roll towards the vent. The vent in Figure 2 of the two right cells is towards the top of the x-ray. The negative end of the cells is the bottom of the x-ray. Cell pair 3A appears different in that the left cell of 3A looks to have the jelly roll pushed down into the negative end and the negative end is still relatively flat. It is for this reason; this cell group was requested to be CT scanned and will be discussed later in this section.

Eskra Technical Products, Inc.

2595 County Rd I Saukville, WI 53080 560 Technology Way STE #7 Saukville, WI 53080
Office/Lab/Shop (262) 235-4068

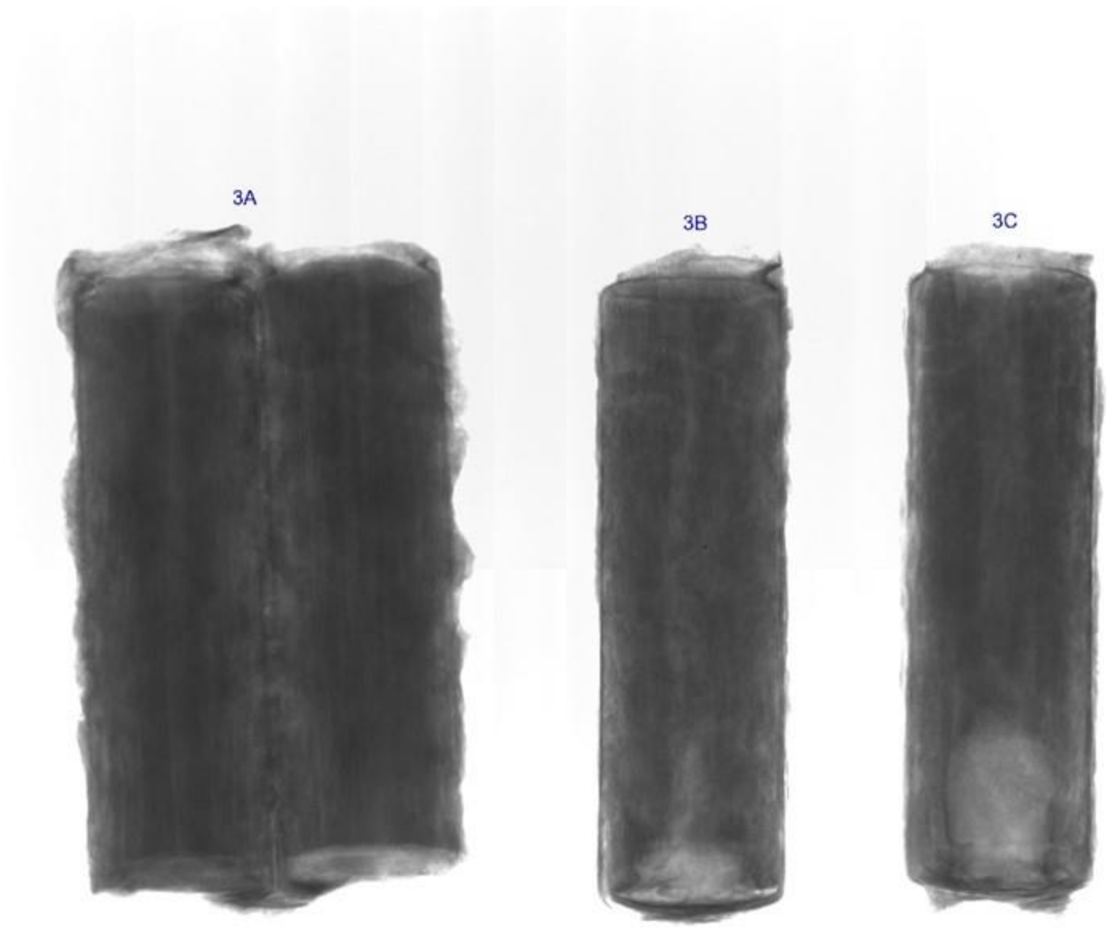


Figure 2. X-ray of Cells 2A, 2B and 2 C

ETP
Eskra Technical Products, Inc.

2595 County Rd I Saukville, WI 53080 560 Technology Way STE #7 Saukville, WI 53080
Office/Lab/Shop (262) 235-4068

Figure 3 shows the x-ray image of cell 4A. This image shows that the jelly roll has been ejected and that the cell can shows the rounding of the negative end of the cell and also expansion of the primary or roll crimp at the positive end of the cell can. This is typical of a cell that was exposed to heat and underwent a thermal runaway. It is not a cell that is causal and can be set aside.

Figure 3. Cell 4A

Eskra Technical Products, Inc.

2595 County Rd I Saukville, WI 53080 560 Technology Way STE #7 Saukville, WI 53080
Office/Lab/Shop (262) 235-4068

Figure 4 shows the x-ray of cells 4B, 4C, 4D, 4E, 4F and 4G. All of these cells show signs of being attacked by fire rather than being the origin.

Figure 4. X-ray of Cells 4B, 4C, 4D, 4E, 4F and 4G

ETP
Eskra Technical Products, Inc.

2595 County Rd I Saukville, WI 53080 560 Technology Way STE #7 Saukville, WI 53080
Office/Lab/Shop (262) 235-4068

Figure 5 shows the x-ray of cells 4H, 4I, 14A, 14B and 14C. Most of these cells look similar to those of **Figure 4.** All but 4H show gas in the base of the cell. 4 H appears to have the gas in the center of the cell. Due to this abnormality the cell was requested to be CT scanned.

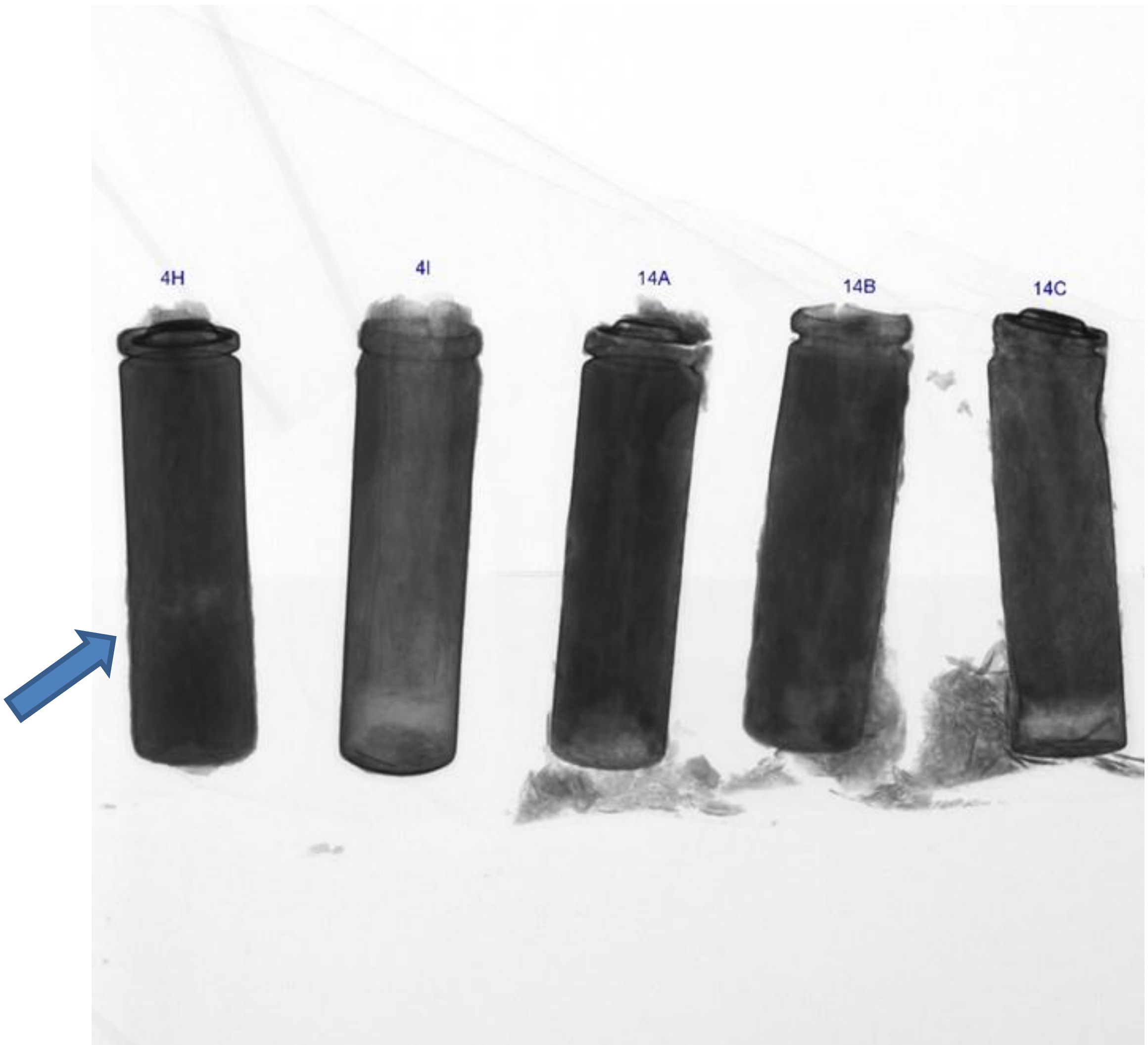


Figure 5. X-ray of Cells 4H, 4I, 14A, 14B and 14C

Eskra Technical Products, Inc.

2595 County Rd I Saukville, WI 53080 560 Technology Way STE #7 Saukville, WI 53080
Office/Lab/Shop (262) 235-4068

Figure 6 shows the x-ray of cells 14D and 14E. Again, these cells have expelled the jelly rolls and exhibit classic signs of being attacked by fire. **Figure 7** shows the x-ray of cell 15A which again appears to be a cell that has been attacked by fire and not an origin.

Figure 6. X-ray of cells 14 D and 14 E

Figure 7. Cell 15 A

Eskra Technical Products, Inc.

2595 County Rd I Saukville, WI 53080 560 Technology Way STE #7 Saukville, WI 53080
Office/Lab/Shop (262) 235-4068

Figure 8 is a cross section of cells 3A that were CT scanned. In this image you can see that both cells look as if they were attacked by fire in that; there are gas pockets that were generated on the negative ends and elongation on the primary crimp on both cells.

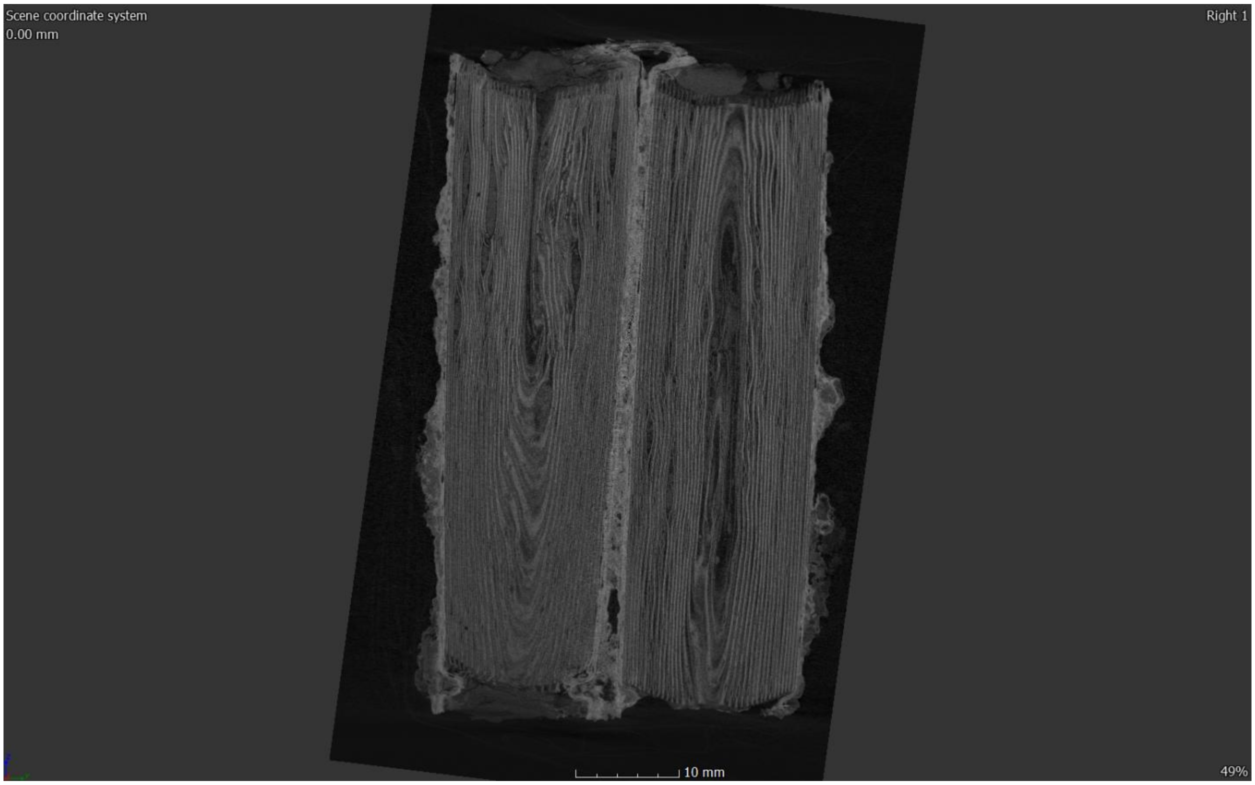


Figure 8. CT Cross Section of Cell group 3A Showing Heat Damage.

Eskra Technical Products, Inc.

2595 County Rd I Saukville, WI 53080 560 Technology Way STE #7 Saukville, WI 53080
Office/Lab/Shop (262) 235-4068

Figure 8 shows the cross section of cell 4H. This image shows that there is some bowing on the negative end of the cell but that the gas generation which created the void in the center of jelly roll appears to have pushed the jelly roll into the bottom and top of the cell.

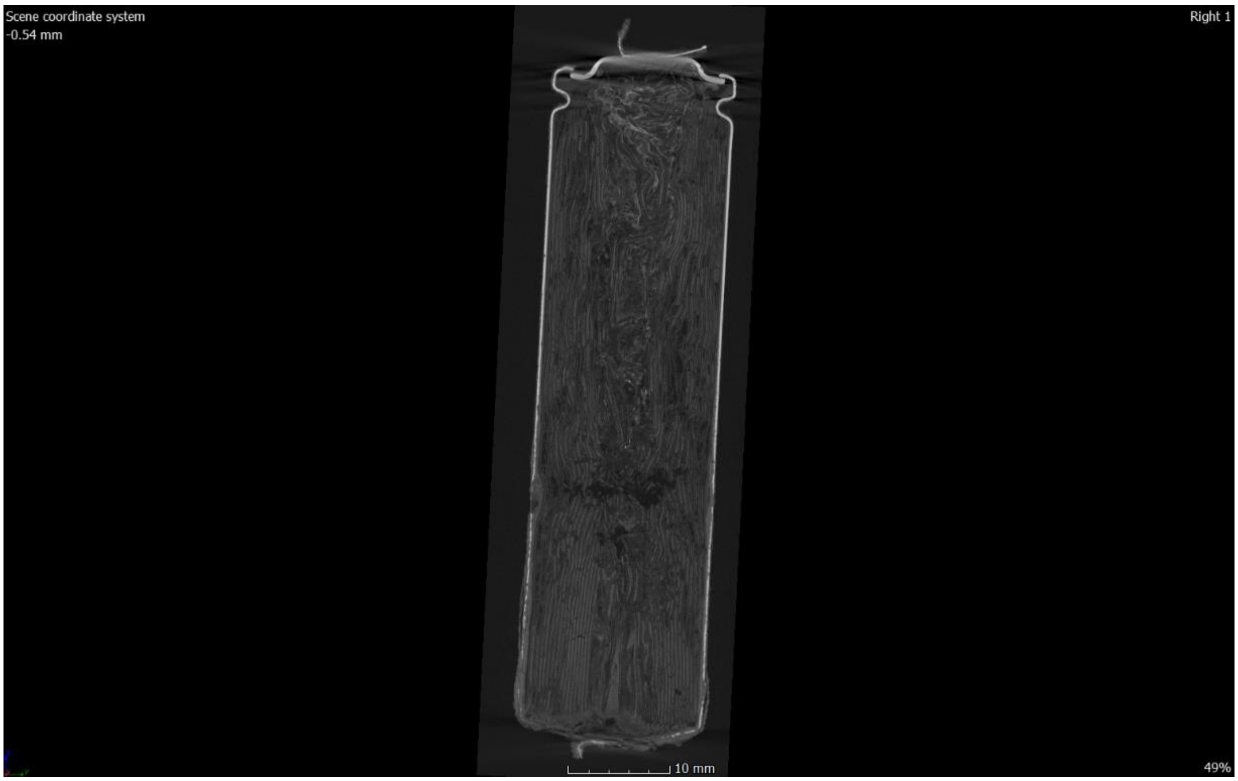


Figure 8. CT Cross Section of Cell 4H

Eskra Technical Products, Inc.

2595 County Rd I Saukville, WI 53080 560 Technology Way STE #7 Saukville, WI 53080
Office/Lab/Shop (262) 235-4068

Figure 9 shows an axial cross section at the area of that void along with the cell slice in Figure 8. What can be seen from this slice is that the void started internal to the jelly roll and radiated out in all directions. The image to the left shows that most of the jelly roll is still intact along its outer wraps. This indicates that the cell was not attacked by fire but caused the fire.

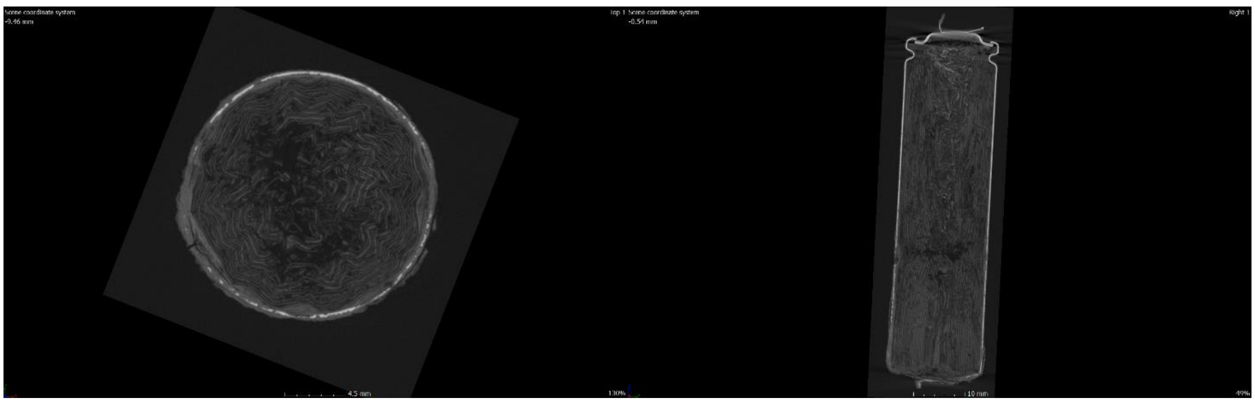


Figure 9. Longitudinal and Axial Cross Sections of Cell 4H

7-Conclusion

The cause of the fire was cell labeled 4H. It developed an internal short. Due to the damage to the cell positive manufacturer identification was not possible via CT scan. The cell is possibly an LG Chem. A destructive analysis would have to be done to be more definitive on the manufacturer.

The findings of Mike Eskra are either matters of fact or professional opinions, formulated within a reasonable degree of engineering certainty, based on the information and evidence available at the time of the evaluation.

Report prepared by:

Michael D. Eskra

Michael D. Eskra
CFEI, CFII, CVFI, PMP

Eskra Technical Products, Inc.

2595 County Rd I Saukville, WI 53080 560 Technology Way STE #7 Saukville, WI 53080
Office/Lab/Shop (262) 235-4068

Appendix A
Over Discharge Supporting Information

Effect of Overdischarge on Li-ion Cells

Dr. Rodney LaFollette and Michael Eskra
Eskra Technical Products
Saukville, WI 53080

Abstract
Overdischarge of lithium ion cells can cause a loss of performance as well as increased safety issues. The reasons for this are several. Overdischarge (discharging of cells below recommended minimum potential) causes damage to the SEI layer and can cause dissolution of the copper current collector used to support negative electrodes. During subsequent cycling of over discharged cells, both the remains of the SEI layer and copper can and will redeposit in the cell, causing loss of capacity of the negative electrodes and/or cell shorts. Overdischarge causes disintegration of the solid-electrolyte interface (SEI) layer on the negative active material. The SEI layer can subsequently regrow upon healthy SEI layer areas leading to cell shorting. Repair of SEI layers over repeated charge/discharge cycling, after over discharge of cells may not be possible. Overdischarge can alter SEI composition by incorporation of copper and/or impurities from the positive electrodes. Heat is evolved from overdischarged cells from changes in the SEI layer and Cu dissolution. In addition to negative electrode changes, positive electrodes can be also affected by severe overdischarge, from loss of crystal structure.

Introduction

Thermal runaway in lithium-ion (Li-ion) cells can be induced by several factors, including manufacturing defects, exposure to very high external temperatures, or mechanical abuse of damage. The safety of (Li-ion) cells also depends in part on the way they are used. This is particularly true if cells are operated outside of the safe potential range. Overcharge (charging a cell at excessively high potential or significantly beyond the rated cell capacity; mAhr) is known to damage cells and/or create safety hazards. Overdischarge (discharge of a cell below the minimum safe value or beyond the rated cell capacity) can also degrade Li-ion cells and cause unsafe conditions.

Overdischarge of cells can be prevented using proper control circuits on individual cells, that stop discharge when the cell potential reaches the minimum (cutoff) potential. If multiple cells are connected in series without monitoring and control of individual cells, there is a risk of overdischarging weaker cells. In addition, operating cells at very high rates during either charge or discharge, such as during high current pulses, can temporarily cause the local potentials values adjacent to the electrode surfaces, to be either too high or too low. This is especially true for cells or batteries that are operated at very low temperatures. Overdischarge can also take place after the discharge is shut off by the control circuit (for having reached the minimum cutoff potential), if a trickle discharge current is used to operate the control circuit. Internal self-discharge of discharged cells allowed to sit at open circuit for extended time can also be overdischarged.

Li-ion cells rarely fail directly due to overdischarge; rather they fail in subsequent charging. There are physical and chemical changes to the cell, particularly the negative electrode, that make normal

ETP
Eskra Technical Products, Inc.

2595 County Rd I Saukville, WI 53080 560 Technology Way STE #7 Saukville, WI 53080
Office/Lab/Shop (262) 235-4068

healthy recharging of the cell difficult or impossible. This report contains a survey of reported studies of the effects of overdischarge on Li-ion cells, particularly with respect to safety. Before that some evidence of gas evolution in the cells from the Coleman lantern fire will be briefly presented.

Fire Attack vs. Over Discharge and Recharge

Long term storage of over discharge cells will usually show bulging at the bottom of their containers upon recharging. This type of swelling is caused by the significant rise of internal cell pressure due to gas evolution, rather than damage from a fire external to the cells. As will be shown in this report, overdischarge of a Li-ion cell leads to gas evolution. (This is in contrast to healthy cells undergoing fire attack which will cause bulging of the negative end from thermal decomposition of electrolyte and separator). In a pouch cell this is mainly manifest in increased cell thickness (due to the buildup of additional gaseous species). In a more constrained cell configuration, such as a spirally-wound 18650 cell (housed in a sealed steel can), the presence of evolved gases is manifest in an increase in internal pressure, and possibly in bulging of the cell can.

To further illustrate the buildup of pressure, we use the well-known ideal gas law, $P=nRTV$

Where P is the pressure, n is the number of moles of the gas, R is the Universal Gas Constant, T is the temperature, and V is the volume of the gas (which is essentially constant inside of the cell). Pressure increases with temperature, and it increases with the number of moles of gas. The cell when first fabricated contains a small amount of gas. As gas is evolved, the number of moles of gas goes up quickly[1]. The number of moles can go from an equivalent of 1 to 18 during over discharge. It does not take a great deal of gas evolution to increase the pressure to several times its initial value; pressures of several tens of psi are easily achieved. As the cell is recharged it is not uncommon for T to go from 20 to 60. Most 18650 Li-ion cells have a built-in pressure relief valve, to vent gas when the pressure reaches a threshold value (such as 140 psi). Still, poorly constructed cells can have a non-functioning relief valve, or a container that can bulge before the pressure reaches the threshold for venting gas. The net effect is that P can increase substantially and would cause distortion of the flat bottom of the 18650 prior to venting of the cell during the over discharge scenario of the Coleman lantern.

[1] It does not matter what type of gas molecules are involved; one mole of hydrogen gas, the lightest gas known, leads to the same pressure as much heavier gases, such as oxygen, nitrogen or water vapor (at the same temperature, and in the same volume).

Overview of Overdischarge Experiments

A number of studies have been reported on the effects of overdischarge of Li-ion cells. Essentially all these studies were done with commercial Li-ion (or Li-polymer) cells. Most used pouch or prismatic cells; a few were with 18650 cylindrical or coin cells. Unless otherwise mentioned, all tests were done at ambient temperature.

Discharges were typically done at constant current. Charging was done in two stages; the first was at constant current to a cutoff potential (appropriate for the electrode materials and electrolyte); the second stage was at constant potential to a cutoff current. A range of positive electrode materials were used, including $LiCoO_2$, $LiMn_2O_4$, NMC, NCA, and $LiFePO_4$. Carbon negative active materials were used, along with common organic liquid electrolytes. Microporous polyolefin separators were used.

ETP
Eskra Technical Products, Inc.

2595 County Rd I Saukville, WI 53080 560 Technology Way STE #7 Saukville, WI 53080
Office/Lab/Shop (262) 235-4068

Overdischarge was usually done to a pre-determined level, such as 2 – 15% of the rated discharge capacity. In some cases, overdischarge was done to a set cell potential, usually 2.2 V – 0.0 V. Occasionally the potential was then held at this level for a set time before subsequent charging.

Maleki and Howard (1) studied overdischarge of commercial $LiCoO_2$/C pouch cells (785 mAhr nominal). Their work focused primarily on cell capacity effects rather than safety. Cells were discharged at moderate rates to the standard cutoff minimum potential, and then at a much lower rate to various lower potentials (2.0 V – 0.0 V). Having reached the targeted (low) potential, they were held at those potentials for 72 hours. They were then subjected to five charge/discharge cycles under more normal conditions (4.2 V – 3.0 V). This entire process was repeated five times, so that cells were held for 360 hours at the lower potentials and operated through 25 charge/discharge cycles. All cells showed irreversible capacity loss of 2 – 16% (overdischarge potentials of 2.0 – 0.5 V). Following these exercises, the cells were operated through one hundred additional normal (4.2 V – 3.0 V) charge/discharge cycles.

Many of the cells were then exposed to aggressive overcharge conditions. This resulted in further capacity loss of 8 – 26% (again for overdischarge potentials of 2.0 V – 0.5 V). Cells that were discharged to 0.0 V suffered greater damage, in some cases 65% loss in capacity over the same conditions. One of the cells taken down to 0.0 V developed an internal short, which was attributed to Cu deposition. These (0.0 V) cells also suffered large impedance increases and swelling (due to gas evolution in the cells). Thus, the fade rate became higher for overdischarged cells, even when cycling was (later) done under more safe conditions. *Furthermore, as stated earlier, the deleterious effects of overdischarge are usually manifest in subsequent charging of the cell*. In the case of the cell that developed a short, very dangerous conditions could well develop, particularly with prolonged charging.

Maleki and Howard, in citing Kishiyama et al. (2), noted that overdischarge to 0.0 V can result in significant levels of Cu dissolution, which is the main reason for the capacity loss of cell on overdischarge. *They also noted that the SEI layer decomposes if the potential of the negative electrode reaches 3.5 V* (vs. Li/Li^+).

Citing Zhao et al. (3), they also state that the Cu dissolution is likely when cells are taken to < 0.4 V (vs. Li/Li^+). The Cu dissolution is accelerated by the presence of H_2O and/or HF in the electrolyte, due to decomposition of the SEI layer, which can occur either through abusive conditions or poor manufacturing standards. They also cite Mao (4) in showing that the negative electrode potential can reach 3.8 V in some cells that are overdischarged to 0.0 V. The movement of copper ions through the separator and to the positive electrode then leads to loss of cell capacity and possibly shorting, due to the high potentials that the negative electrodes can be exposed to.

Finally, Maleki and Howard reported significant swelling of the pouch cells. They attributed this to gas evolution within cells, which was more severe for cells with lower overdischarge potential and longer overdischarge exposure.

Prochazka et al. (5) discharged Sanyo UR1860F cells to 0.0 V for three cycles. Significant degradation of discharge capacity was seen for each cycle (31%, for three cycles; resistance up 51%). No significant overheating from their charge/discharge treatment was observed.

ETP
Eskra Technical Products, Inc.

2595 County Rd I Saukville, WI 53080 560 Technology Way STE #7 Saukville, WI 53080
Office/Lab/Shop (262) 235-4068

Erol et al. (6) discharged commercial $LiCoO_2$/C button cells down to 2.2 V. Cells were subsequently cycled under fairly standard conditions (4.2 V – 3.0 V). The cells suffered from increases in cell impedance; however, the degradation was reversible for most cells.

In contrast, Lai et al. (7) discharged commercial NMC/C pouch cells into reversal (up to 20% overdischarge). For high levels of overdischarge (20%), the cells suffered significant irreversible capacity loss. They found that copper had dissolved from the negative electrode during overdischarge, and then subsequently re-deposited, mostly on the surface of the negative active material. Some copper deposited elsewhere in the cell, such as on the positive electrode material. As a result, copper shorts developed between the electrodes during subsequent cell cycling.

Importantly Lai et al. found that when severely overdischarged cells were then overcharged, they had difficulty with charge acceptance. This they attributed to damage to the cell structure, mainly the formation of internal shorts. The leakage current (i.e. that due to small current flow between electrodes through small shorts) could cause further overdischarge if the cells sat at open circuit while discharge. The presence of internal shorts could clearly lead to catastrophic cell failure in some cases.

They also found that many cells that were only modestly overdischarged could be restored to normal functioning if they were fully charged and then allowed to sit at open circuit for extended time (100 days). The self-repair process though could not be accomplished in short time periods, so that overdischarged cells could show abnormal charging behavior, unless first charged and allowed to rest for several weeks.

Numerous other studies showed similar results, especially with respect to the fate of copper. Love and Gaskins (8) overdischarged Li-polymer[2] pouch cells ($LiCoO_2$/C). Cells exhibited substantial loss of negative electrode capacity, depending on the degree of overdischarge. For high levels of overcharge, cells swelled, the result of gas evolution. These cells also showed pitting of the aluminum foil used to support positive electrodes (along with copper dissolution and precipitation).

He et al. (9) reported substantial copper dissolution in overdischarged A123 18650 cells, using $LiFePO_4$ as the positive electrode active material. Copper reprecipitated throughout the cell on subsequent charge/discharge cycling. This in turn led to the formation of copper dendritic growths, often resulting in cell shorts, which as noted could lead to catastrophic cell failure.

[2] Li-polymer cells are essentially Li-ion cells with a polymer electrolyte.

Brand et al. (10) discharged experimental cells using a variety of positive electrode active materials (NCA, NMC, $LiFePO_4$, others), and carbon negatives. They did careful measurements of heat generation in the cells. These workers also found when discharge potentials dropped below a minimum value (different for each cell chemistry), there were accelerated temperature increases in the cell, with NMC/C showing the highest increase. The temperature increase was found to result from breakdown of the SEI layer as well as electrolyte reduction. Also, when negative potential reaches 3.4 – 3.5 V (vs. Li/Li^+), Cu oxidized, further heating cell. This was consistent with the results of Kishiyama et al. (2). During subsequent charge/discharge cycling Cu deposited throughout the cells. This in turn frequently caused shorts between negative and positive electrodes, which in turn caused additional temperature rise.

Eskra Technical Products, Inc.

2595 County Rd I Saukville, WI 53080 560 Technology Way STE #7 Saukville, WI 53080
Office/Lab/Shop (262) 235-4068

Zhang et al. (11) overdischarged $LiCoO_2$/C (MCMB) cells to different levels (2-15% beyond the rated capacity), and then cycled them 1000 times at more healthy conditions. The discharge rate was 0.6C. The $LiCoO_2$ and MCMB retained their structures; however, there were appreciable capacity loss for the negative electrodes. They found this was due to increased resistance of the SEI layer. Additional losses were due to Cu deposition on negative, for cells overdischarged 15%. Capacity losses from deposited Cu (on the negative active material) were caused by hindered Li/Li+ intercalation/deintercalation.

Zheng et al. (12) tested $LiFePO_4$/C cells, discharged to 1.5 V, 1.0 V, 0.5 V, 0.0 V. Afterwards all cells were subjected to 110 charge/discharge cycles (under normal conditions). Capacity losses were significant, and dependent on the overdischarge potential (for the first discharge). Results were 24.9% for 0.0 V to 12.6% for 0.5 V. An additional 110 cycles were applied to the same cells. Additional capacity losses were observed, 7.8% (0.5 V cells) and 24.46% (0.0 V cells). Serious loss of Li and active negative material was observed in the 0.0 V cells. This was caused (presumably) by dissolution/breakdown of SEI. Gas was generated in both types of cells, mainly H_2, CH_4, C_2H_6. The presence of gaseous hydrocarbons they took as evidence that there was some electrolyte decomposition at the negative/electrolyte interface. No real change was observed in $LiFePO_4$ structure. They did though report change in the surface chemistry of graphite negatives, which caused increased impedance.

Guo et al. (13) also found that Cu deposits were the result of severe overdischarge. This can lead to reduced efficiency and capacity, as well as internal shorts. Non-shorted, overdischarged cells can often be regenerated if not severely overdischarged (< 12%). However, some overdischarged, recharged cells showed reduced coulombic efficiency (12 – 14.5%). Over 14.5% of the cells tested could not be recharged.

Li et al. (14) also found that overdischarge leads to swelling. Similar observations were made by Maleki and Howard (1). This was caused by 1) Cu dissolution; inclusion of Cu in SEI; 2) Cu reduction at negative during charge, reducing coulombic efficiency; and 3) SEI decomposition, with gas evolution leading to bulging. Use of NCM (rather than $LiCoO_2$) lowered swelling.

The main capacity losses took place at the negative electrodes in these studies. Shu et al. (15) however studied cathode-limited experimental cells, where the cells were discharged to 1.0 V. $LiFePO_4$, $LiMn_2O_4$, and $LiNiO_2$ were used as cathode materials. $LiFePO_4$, $LiMn_2O_4$ cathodes are fairly stable when cells are overdischarged to 1.0 V. $LiNiO_2$ is more vulnerable to breakdown (loss of structure). When discharged to 0.0 V, all three materials become (irreversibly) amorphous.

Gas evolution was also examined by Hashimoto et al. (16). They studied H_2 gas evolution from overdischarged $LiMn_2O_4$/C cells. They found that the gas evolution resulted from decomposition of the SEI layer on the negative active material. The origin of the hydrogen was impurities in the positive electrode active material, not the electrolyte. As the cells were further cycled the SEI layer on the negative electrode material, which was reconstituted during cycling, became increasingly rich in hydrogen. The SEI layers thickened during cycling, leading to increasing hydrogen evolution and higher negative potentials.

Finally, Jeevarajan et al. (17) studied substantial reversal of cylindrical cells that were then placed in storage. In these conditions the (steel) cell can was corroded, and iron was found in the separator. They found that parallel-connected cells showed very little degradation when subjected to deep

ETP
Eskra Technical Products, Inc.

2595 County Rd I Saukville, WI 53080 560 Technology Way STE #7 Saukville, WI 53080
Office/Lab/Shop (262) 235-4068

discharge. However, series-connected cells often performed poorly under the same conditions. They attributed this to poorly matched cells in the string, which led to the weaker cells being overdischarged more deeply than other cells.

Safety Implications of Overdischarge

As pointed out in these studies, high levels of overdischarge can result in Cu dissolution and then re-deposition in either on the negative electrode, positive electrode or in the separator. This can cause the formation of internal shorts, via Cu dendritic growths. The growth of Cu dendrites is possible after a single overdischarge, especially if subsequently charged aggressively.

Changes in the SEI layer invariably took place due to overdischarging. In some cases, the SEI layer can disintegrate, raising the increased possibility of catastrophic cell failure during subsequent charging. In other situations, it is made more resistive, due to incorporation of either copper of other species such as hydrogen or growth. Thicker SEI layers of course causes higher internal cell resistance. Cu deposition is the most important result of overdischarge, that affects the health or composition of the SEI layer on the negative electrode surface.

All overdischarged cells showed evidence of gas buildup in cells. The composition of the gases varied from study to study, but the fact that gas evolution took place is established. These two factors (Cu dissolution/precipitation and alteration of the SEI layer) are the principal safety concerns for overdischarged Li-ion cells. Care should therefore be taken to prevent overdischarge for maximum battery safety.

References

1 Maleki, H., Howard, J., "Effects of Overdischarge on Performance and Thermal Stability of a Li-ion Cell," Journal of Power Sources, **160**, p. 1395 (2006).

2 Kishiyama, C., Nagata, M., Piao, T., Dodd, J., Lam, P-N., Tsukamoto, H., Abstract 245, Proceedings of the 204th Electrochemical Society Conference, Orlando, FL (2003).

3 Zhao, M., Kariuki, S., Dewald, H., Lemke, F., Staniewicz, R., Phichita, R., Marsh, R., Journal of the Electrochemical Society, **147**, p. 2874 (2000).

4 Mao, Z., Abstract 304, Proceedings of the 204th Electrochemical Society Conference, Honolulu, HI (2006).

5 Prochazka, P., Cervinka, D., Martis, J., Cipin, R., Vorel, P., "Li-ion Battery Deep Discharge Degradation," ECS Transactions, **74**, No. 1., p. 31 (2016).

6 Erol, S., Orazem, M., Muller, R., "Influence of Overcharge and Over-Discharge on the Impedance Response of $LiCoO_2$/C Batteries," Journal of Power Sources, **270**, p. 92 (2014).

7 Lai, X., Zheng, Y., Zhou, L., Gao, W., "Electrical Behavior of Overdischarge-Induced Internal Short Circuit in Lithium-Ion Cells," Electrochimica Acta, **278**, p. 245 (2018).

8 Love, C., Gaskins, A., "Performance Loss of Lithium Ion Polymer Batteries Subjected to Overcharge and Overdischarge Abuse," Naval Research Laboratory Publication NRL/MR/6110—12-9455 (2012).

9 He, H., Liu, Y., Liu, !., Li, Z., Xu, F., Dun, C., Ren, Y., Wang, M-x., Xie, J., "Failure Investigation of $LiFePO_4$ Cells in Over-Discharge Conditions," Journal of the Electrochemical Society, **160**, No. 6, p. A793 (2013).

10 Brand, M., Glaser, S., Geder, J., Menacher, S., Obpacher, S., Jossen, A., Quinger, D., "Electrical Safety of Commercial Li-ion Cells Based on NMC and NCA Technology Compared to LFP Technology," World Electric Vehicle Journal, **6**, p. 572 (2013).

Eskra Technical Products, Inc.

2595 County Rd I Saukville, WI 53080 560 Technology Way STE #7 Saukville, WI 53080
Office/Lab/Shop (262) 235-4068

11 Zhang, L., Ma, Y., Cheng, X., Du, C., Guan, T., Cui, Y., Sun, S., Zuo, P., Gao, Y., Yin, G., "Capacity Fading Mechanism During Long-Term Cycling of Over-Discharged $LiCoO_2$/Mesocarbon Microbeads Battery," Journal of Power Sources, **293**, p. 1006 (2015).
12 Zheng, Y., Qian, K., Luo, D., Li, Y., Lu, Q., Li, B., He, Y-B., Wang, X., Li, J., Kang, F., "Influence of Over-Discharge on the Lifetime and Performance of $LiFePO_4$/Graphite Batteries," Royal Society of Chemistry Advances, **6**, p. 30474 (2016).
13 Guo, R., Lu, L., Ouyang, M., Feng, X., "Mechanism of the Entire Overdischarge Process and Overdischarge-Indices Internal Short Circuit in Lithium-ion Batteries," Scientific Reports, Nature, 6:30248, July (2016).
14 Li, H-F., Gao, J-K., Zhang, S-L., "Effect of Overdischarge on Swelling and Recharge Performance of Lithium Ion Cells," Chinese Journal of Chemistry, **26**, No. 9 (2008).
15 Shu, J., Shui, M., Xu, D., "A Comparative Study of Overdischarge Behaviors of Cathode Materials for Lithium-Ion Batteries," Journal of Solid State Electrochemistry, **16**, No. 2, p. 819 (2012).
16 Hashimoto, M., Yamashiro, M., Ichihashi, T., Toda, A., Miyazaki, T., Fujieda, S., "Mechanism of Gas generation in Lithium Ion Batteries by Overdischarge," ECS Transactions, **69**, No. 20, p. 17 (2015).
17 Jeevarajan, J., Strangways, B., Nelson, T., "Hazards Due to Overdischarge in Lithium-ion Cylindrical Cells in Multi-cell Configuration," NASA Battery Workshop, November (2010).

ETP
Eskra Technical Products, Inc.

2595 County Rd I Saukville, WI 53080 560 Technology Way STE #7 Saukville, WI 53080
Office/Lab/Shop (262) 235-4068

CV

Michael D. Eskra
2595 County Road I
Saukville, WI 53080
262-707-5855 Cell
262-235-4068 Office/Lab/Fax
262 2681753 Fax
mikeeskra@aol.com

Summary:

Senior executive and technical manager with 30+ years experience in the energy, power source and battery industry, including business strategy, planning and operations, technology development and deployment, material development, manufacturing and power systems electronics. Special expertise in tactical planning, operations, marketing and business development in the Energy, Battery and Advanced Automotive Propulsion areas. Broad working knowledge of energy, battery and power source development, battery products, processes, vendor development, WCM and FMEA, as well as global strategies and turn around in the strategic power systems industry.

Experience:

1996-Present: Owner, Eskra Technical Products, Inc., Saukville, WI

- Designed and developed manufacturing processes for lithium ion, lithium polymer, nickel metal hydride, lead acid, zinc bromine, nickel hydrogen, lithium iron disulfide and silver zinc battery technologies.
- Developed low cost solvent free processing for primary lithium battery cathodes(pat pen)
- Developed solvent free lithium ion electrode manufacturing process.(pat pen)
- Specialty battery manufacturing and assembly of battery packages for mission specific applications
- Developed low polymeric ceramic separator for lithium ion/polymer batteries (pat pen)
- Developed and executed strategic acquisition and business plans for clients in renewable energy, rechargeable and primary battery areas.
- Provide technical and staffing recommendations to clients in the battery, aerospace and government agencies.

ETP
Eskra Technical Products, Inc.

2595 County Rd I Saukville, WI 53080 560 Technology Way STE #7 Saukville, WI 53080
Office/Lab/Shop (262) 235-4068

- Provide Strategic planning, market analysis and acquisition targets for battery and aerospace companies.
- Wrote business plans for flexible power sources, micro batteries, renewable energy and acquisition and mergers, technology development roadmaps.
- Developed key development and technology plan for smart energy grid.
- Provided technical and business assessment to VC and Angel investors
- Failure Mode and Effect of energy and power system products for insurance investigations.
- Battery and power source failure investigation and litigation.
- Developed waste to liquid fuel process, waste to solid clean fuel processes.
- Assisted in business plan development for gearless wind turbine and presentations to potential investors-designed on-demand battery storage building block
- Member of the SAE Aerospace Power Systems Committee
- Provide support for Defense Logistics Agency on batteries through BATTNET
- Specialty battery and other power source packaging for niche applications
- Oversight management for ANSI and battery testing and technology facility

1999-2005: President and COO, Director, Electro Energy Inc., Danbury, CT (Consultant and Employee)

- Brought failing Research and Development company to successful public company status.
- Responsible for bringing multiple government and commercial programs in house.
- Program Manager for multiple government contracts and commercial contacts.
- Increased power by 100% and capacity by 30% for the Army and 150% for the Navy efforts
- Developed 1MW 250 Volt rechargeable battery/1.4MW 350 Volt battery systems.
- Provided hands-on technical and management oversight on all development projects.
- Achieved successful, on schedule delivery for the first time since company inception.
- Developed processes and designed equipment to take product from development to manufacturing.
- Acquired manufacturing subsidiary in complementary technology.
- Raised $5.5M outside capital.
- Reverse merger with public shell, June 2004, EEEI.ob
- NASDAQ Small Cap, December 2004, EEEI, $200+M market cap, January 2005

ETP
Eskra Technical Products, Inc.

2595 County Rd I Saukville, WI 53080 560 Technology Way STE #7 Saukville, WI 53080
Office/Lab/Shop (262) 235-4068

- All stock purchase of large manufacturing facility
- Positioned company for $25M second round of financing and additional acquisition
- Developed team of engineers and specialists for advanced nickel metal hydride and lithium ion chemistries.

1991-1996: Program Manager, Advanced Technology Vehicles, GM Corp, Warren, MI

- Principle negotiator and contract lead for United States Battery Consortium (USABC).
- Formed necessary partnerships and teaming arrangements required to develop advanced battery and material technology for electric and hybrid vehicles.
- Developed base agreements and worked to alleviate anti-trust concerns.
- Managed over $150M annually in development contracts.
- Oversaw National Laboratory development contracts and promoted strategic planning for long term US technology including uniform CRADA.
- Coordinated technical and business direction of the automotive partnership through various committees.
- Represented GM in the partnership, committees, Partnership for New Generation Vehicles (PNGV), the Departments of Energy and Commerce, the White House, Vice-President Gore and staff.
- Prepared Congressional testimony and circumvented freedom of information requests.
- Participated in Vice Presidential and Congressional reviews.
- Initiated novel material development efforts in polymer based systems.
- Supported electric drive train propulsion development and commercialization for all electric vehicle and hybrid electric vehicle platforms including battery packs and battery management systems.
- Reviewed technology programs for Departments of Energy, Defense, NASA and Commerce.
- Identified and coordinated funding for Lithium ion, polymer, nickel metal hydride, bipolar lithium, iron disulfide, sodium sulfur and lead acid battery systems relating to safety, advanced materials and designs.

1986-1991: Manager, Advanced Battery Engineering, Johnson Controls Inc., Milwaukee, WI

- Formed four business units to develop new opportunities for Johnson Controls, Inc. in the energy, advanced battery, plastics and automotive technology areas.

ETP
Eskra Technical Products, Inc.

2595 County Rd I Saukville, WI 53080 560 Technology Way STE #7 Saukville, WI 53080
Office/Lab/Shop (262) 235-4068

- Formulated and executed international, multi-company technology cross licensing agreements related to multiple technologies and markets.
- Developed and executed operational business plans to move technologies from development to commercialization.
- Grew start ups to $12M in sales with less than $1M of total internal investment.
- Utilized government funding to leverage organizations into new, profitable, commercial businesses.
- Obtained space qualification of Common Pressure Nickel Hydrogen (IPV) technology in under 2 years, presently the most flown spacecraft battery.
- Responsible for Common Pressure Nickel Hydrogen (CPV), Bipolar lead acid (pulse Power), Zinc Bromine (now ZBB) and Advanced Lead Acid (EV, consumer electronics, SKI and Pulse Power). Designed and built 100MJ battery system, 40 kWh and 20 kWh electric vehicle packs.
- Developed high strength, chemically stable conductive and on conductive polymer materials.
- Identified acquisition targets for main business, formulated deal outlines

1981-1986: Process Engineer, Quality Manager, Plant Superintendent
Johnson Controls Inc., Milwaukee, WI

- Turn-around of three under-performing battery manufacturing plants, improving production by 50% while improving quality.
- Managed Pilot Plant Operations, 1000 SLI batteries/day
- Developed and/or modified equipment and processes to improve productivity, quality and profitability.
- Developed advanced manufacturing line.
- Negotiated and revised Labor Union contracts.
- Trained corporate manufacturing staff and provided technical support to 13 manufacturing plants and two plastic plants.
- Responsible for five new product introductions (SLIG).
- Developed staff to accomplish what many thought was impossible performance and business targets.
- Temporary Plant Engineering Mgr, Plant Superintendent, Plant Manager at Fullerton, CA, Atlanta, GA, Toledo OH. Louisville, KY, Dallas TX as needed to support Battery Group

ETP
Eskra Technical Products, Inc.

2595 County Rd I Saukville, WI 53080 560 Technology Way STE #7 Saukville, WI 53080
Office/Lab/Shop (262) 235-4068

1980-1981: Converting Line Manager, Proctor and Gamble, Inc. Green Bay, WI

- Improved shift performance by 100%
- Reduced hourly absenteeism by 200%
- Responsible for Charmin, White Cloud and Puffs lines

Five U.S. Patents related to materials, batteries and manufacturing
300+ Papers and Articles Published.

U.S. Security Clearances

Education: Masters of Engineering Management (45Credits), Milwaukee School of Engineering
BS Chemical Process Engineering, University of Wisconsin, Milwaukee
Certified Fire Explosion Investigator, Certified Fire Instructor Certified Vehicle Fire Investigator
Program Management Professional

Memberships:
AICHE-American Institute of Chemical Engineers
SAE-Society of Automotive Engineers
NAFI-National Association of Fire Investigators
IAAI-International Association of Arson Investigators
PMI-Project Management Institute
NDIA-National Defense Industry Association
NASP-National Association of Subrogation Professionals

Battery Related Program Management Experience

1. $3,400,0000 “Zinc Bromine for Electric Vehicles”, Sandia National Laboratories 1986
2. $750,000 “High Power Lead Acid Batteries for DEW”, USAFWP 1988
3. $3,800,000 “Zinc Bromine for Load Leveling”, Sandia National Laboratory 1988
4. $250,000,000 United States Battery Consortium 1990, nickel metal hydride and lithium ion for Electric Vehicles

Eskra Technical Products, Inc.

2595 County Rd I Saukville, WI 53080 560 Technology Way STE #7 Saukville, WI 53080
Office/Lab/Shop (262) 235-4068

5. $30,000,000 Partnership for New Generation Vehicle, lithium ion and nickel metal hydride for hybrid electric vehicle.

6 $700,000 "Nickel Metal Hydrogen for Energy Storage, Department of Energy 1998

7. $60,000, BMDO Phase I, April 2000, "High Power Nickel Metal Hydride" managed by the Navy China Lake Naval Air

8. 1,999,036, NAVAIR F-17, F-18, F-16, August 2000, "Nickel Metal Hydride Development for Aircraft."

9. $412,375, NASA Glenn Research Center, January 2001, "Flight Weight Battery Option for Low Earth Orbit."

10. $1,600,000, USAF, February 2001, Manufacturing Technology Development.

11. $807,435, US Army CECOM, July 2001, Bipolar Wafer Ni-MH Electrochemical System.

12. $3,820,000, USABC Partnership for New Generation Vehicle, August 2001, "Hybrid Vehicle Battery."

13. $2,264,127, U.S. Dept. of Energy, January 2002, "Energy Efficiency and Environmentally Friendly Distributed Resources Energy Storage Battery."

14. $99,908, USAF/AFMC, May 2002, "Aero Propulsion and Power Technology, New Hydrogen Storage Electrodes."

15. $809,999, US Army CECOM, July 2002, "Bipolar Wafer (NiMH) Electrochemical System."

16. $489,378, NASA Glenn Research Center, July 2002, "Bipolar Nickel Metal Hydride Battery."

17. $788,104, US Army CECOM, April 2003, "Bipolar Ni-MH Electrochemical Battery System."

18. $854,931, USAF, May 2003, "Bipolar Wafer Cell Ni-MH Aircraft Battery."

19. $500,000, In-Q-Tel, March 2004, "Bipolar Lithium-Ion Battery."

20. $848,788, US Army CECOM, March 2004, "Bipolar Wafer Cell Ni-MH Battery for Army Vehicles."

21. $69,978, Navy STTR, June 2004, "Extremely Power Dense Bipolar Ni-MH Energy Storage System."

ETP
Eskra Technical Products, Inc.

2595 County Rd I Saukville, WI 53080 560 Technology Way STE #7 Saukville, WI 53080
Office/Lab/Shop (262) 235-4068

22. $69,943, Navy SBIR, June 2004, "Low Magnetic Signature, Rechargeable, Modular Battery Technologies for Mine Warfare."

23. $735,666, U.S. Dept. of Energy/Sandia National Labs, June 2004, "Ni-MH Battery for Utility Applications."

24. $300,000, In-Q-Tel Phase I, March 2004, "Development of Bipolar Lithium Ion Cell"

25. $98,647, USAF Phase I, March 2005, "Lithium Batteries for Strategic Missile Flight Testing"

26. $450,000, In-Q-Tel , April 2005, "Lithium Ion Batteries with Cell Specific Energy Greater than 300 Wh/kg"

27. $3,000,0000 BAA No. 0006-08 BATTNET Support to DLA

29 $9,000,000 Power Sources Support 2009

30 $9,500,000 Power Sources Support2010

31. $414,080 BATTNET March 2011 Low Cost Lithium Ion Manufacturing Development

32. $80,000 NAVSEA September 2011, Energy Scavenger, Thermal Battery Replacement

33.) $150,000 DOE Low Cost Lithium Ion Electrode for Bipolar and Prismatic Cells

34.) $149,996 DLA CR123 Low Cost Manufacturing Development and Option

35.) DLA BATTNET Option 2 Period of Performance October 2013 to December 2014

36.) DLA BATTNET Option 3 Period of Performance November 25, 2013 to January 2015

37.) US Army Bipolar Lead Acid $100,000 July 28, 2014

38.) DLA Low Cost Solvent Free Lithium Ion Manufacturing Development $2,475,000 July 2014 to July 2016

39.) US Army Bipolar Lead Acid $1,000,000 May 5, 2016

40.) USAF Rechargeable Thermal Battery for Airborne Operations $150,000

Sample Papers

1.) January 2001 Long Beach CA

Nickel-Metal Hydride Replacement for VRLA and Vented Nickel-Cadmium Aircraft Batteries

ETP
Eskra Technical Products, Inc.

2595 County Rd I Saukville, WI 53080 560 Technology Way STE #7 Saukville, WI 53080
Office/Lab/Shop (262) 235-4068

Michael Eskra[1], Paula Ralston[1], Martin Klein[1], William Johnson[2], John Erbacher[3], Baird Newman[4]

Electro Energy Inc., 30 Shelter Road, Danbury, CT. 06810

NAVAIR, 48298 Shaw Road, Building 1461, Patuxent River, MD 20670

USAF AFRL/PRPB, 1950 Fifth Street, Wright Patterson AFB, OH 45433-7251

NSWC, 300 Highway 361C, Crane, IN 47522

2.) Aerospace Battery Session 2000 Power Systems Conference

Bipolar Nickel Metal Hydride For Aerospace Applications

Electro Energy, Inc.

Authors: Mike Eskra, Martin Klein

(Special thanks to NASA GRC, Department of Energy, PNGV, NAVAIR, USAF)

3.) 39th Power Sources Conference (2 papers)

Bipolar Nickel Metal Hydride for Aerospace

Nickel Metal Hydride High Power Battery

Michael D. Eskra Jack Brown Martin G. Klein

Electro Energy, Inc.

(Special thanks to NASA GRC, Department of Energy, PNGV, NAVAIR, USAF)

Also published in the IEEE magazine

4.) Global Powertrain Congress 2001

Bipolar Nickel Metal Hydride For Automotive Electric Drivetrains

Mike Eskra, Martin Klein, Robert Plivelich

(Special thanks to NASA GRC, Department of Energy, PNGV, NAVAIR, USAF)

5.) 7th Workshop for Battery Development

Nickel Metal Hydride Aircraft Batteries

Mike Eskra, William Johnson (NAVAIR), John Erbacher (WPAFB)

6.) Power Systems Conference 2002

02PSC-69

ETP
Eskra Technical Products, Inc.

2595 County Rd I Saukville, WI 53080 560 Technology Way STE #7 Saukville, WI 53080
Office/Lab/Shop (262) 235-4068

Pulse Power Nickel Metal Hydride Battery

Robert F. Plivelich and Michael D. Eskra

7.) SAE Power Systems Conference 2000

00PSC-123 Bipolar Metal Hydride Batteries for High Power and Aircraft Applications Mike Eskra, Marty Klein, Robert Plivelich Electro Energy, Inc

8.) Hawaiian 4th Battery Conference HBC January 2002

Nickel Metal Hydride PNGV, NAVAIR, USAF

9.) 40th Power Sources Conference June 12, 2002

Bipolar Nickel Metal Hydride Battery

Mike Eskra, Paula Ralston, John Erbacher, Bill Johnson

10.) 5th SAE Power Systems Conference October 29-31, 2002

Bipolar Nickel Metal Hydride Batteries For Aircraft Applications

Mike Eskra, Robert Plivelich, Paula Ralston, John Erbacher, Bill Johnson

11). High Power Bipolar Nickel Metal Hydride Battery for Utility Applications

Michael Eskra, Robert Plivelich.) Energy Storage and Transmission Nov 2003

12.) Scale-Up of Manufacturing Processes for a Bipolar Nickel-Metal Hydride Aircraft Battery

James Landi(a), Martin Klein(a), Mike Eskra(a), John K. Erbacher(b) and Robert Drerup(c)

13.) Energy Efficiency Environmentally Friendly Distributed Resources Energy Storage Battery

Pulse Power Nickel Metal Hydride ESAT 2004 US Department of Energy, Sandia National Laboratory

14.) Pulse Power 350 V Nickel Metal Hydride Battery

Michael D. Eskra, Paula Ralston, Alvin Salkind and Robert F. Plivelich

Brighton, England April 2004

15.) Lithium-ion Fires, Michael D. Eskra, Lithium Battery Safety Meeting 2012

ETP
Eskra Technical Products, Inc.

2595 County Rd I Saukville, WI 53080 560 Technology Way STE #7 Saukville, WI 53080
Office/Lab/Shop (262) 235-4068

16.) Low Cost Flexible Manufacturing for Defense Applications, Michael D. Eskra, Paula K. Ralston, Defense Manufacturing Conference, Orlando FL 2012

17.) Counterfeit Batteries Entering the Supply Stream, Michael D. Eskra, Paula K. Ralston, Defense Manufacturing Conference 2013

18.) Solvent Free Lithium-ion Manufacturing, 2014 Power Sources Conference, Michael Eskra

19.) Battery Safety-Developing a Methodology for Avoiding Risks From Product Failure and Subsequent Subrogation/Wrongful Death-Breakout Discussion Session Battery Safety 2015, Michael Eskra Host

20.) Dry Electrode Processing of Lithium-ion Electrodes, Michael Eskra, Paula Ralston, Lithium Battery Power 2015

21.) Scale Up for Lithium-ion Electrode Manufacturing, Michael Eskra, Paula Ralston 2015 Joint Services Power Expo

22.) Fire and Arson Presentation June 2015 IAAI MN Chapter, Mike Eskra

23.) Additive Safety Separator Manufacturing for Lithium Batteries Power Sources Conference, Mike Eskra, Paula Ralston June 2016

24.) Low Cost JIT Additive Lithium-ion Electrode and Ceramic Separator Manufacturing, Michael Eskra, Paula Ralston, Power Sources Conference 2016

25.) Design and Safety Considerations for Design of Energy Storage Systems, Mike Eskra, Bryan Eskra, ASME Power and Energy Conference June 2016

26.) Fire and Arson Presentation, WI Chapter IAAI, June 2016

27.) ATF Presentation on Battery Fires, Nov 2016

28.) Update on Developments of Solvent Free Manufacturing Process for Lithium Electrodes, Joint Services Power Expo, May 2-4 2017

29.) Creating a Lead Acid Battery Which Can Compete With Lithium-ion, Joint Services Power Expo May 2-14 2017

30.) Fire and Arson Presentation on Battery Fires October 4, 2017 IAAI PA Chapter, Mike Eskra

ETP
Eskra Technical Products, Inc.

2595 County Rd I Saukville, WI 53080 560 Technology Way STE #7 Saukville, WI 53080
Office/Lab/Shop (262) 235-4068

31.) Advanced Lead Acid Battery Staying Competitive, 2018 Power Sources Conference June 11, 2018

32.) Consumer Battery Failures and COTS, 2018 Power Sources Conference June 14, 2018

33.) PAAI-8hr Battery Failures and Analysis June 2019

34.) Battery Fire Forensics, Battery Safety Summit, October 25, 2019

Depositions and Trials

**Plaintiff - The Main Street America Group v. Dell Inc. (Case No: 8:09-cv-1269-T-26TGW, John W. Reis | Cozen O'Connor 301 S. College Street, Suite 2100 | Charlotte, NC 28202 P: 704.376.3400 | F: 704.334.3351 | jreis@cozen.com
www.cozen.com | www.subrogationandrecoverylawblog.com**

Nick Mooney nick.mooney@bromagenlaw.com

**Plaintiff - STJOHN-9831 St. Johns a/s/o Caspellana, Giovanni & Sonia: Catherine Bonilla, Paralegal
Powers, McNalis, Torres & Teebagy P.O. Box 21289 West Palm Beach, FL 33416-1289 (561)588-3000 P (561 588-3705 (fax)
www.powersmcnalis.com email: cbonilla@powersmcnalis.com Deposed and Trial**

Plaintiff - LEE vs IBM. Alabama Laptop Fire, B Johnson, Red Mountain Law Group Johnston Law Group Johnston Law Firm, PC, The Landmark Center, 2100 First Avenue North, Suite 600, Birmingham, Alabama 35203 (205) 328-9445 Ext 600, F(800) 856-9028, brice@johnstonfirmpc.com

Plaintiff - Menser v FCA US, LLC, Eastern District Arkansas Western Division Case 4:15-CV-136 KGB, Martin Bowen, Bowen Law Firm, LLC 121 North Spring Street, Searcy AR 72143

Defense - Metal Conversion Technology, LLC vs Environmental Integrity Company and Charles Bailey Trucking, Inc. Rome Georgia, Steve Miller, Esq. Drew Eckl Farnham, LLC.

Defense, then Plaintiff - Dawna Kay Gold vs SureFire, LLC and Tenergy Corporation, Circuit Court of Rutherford County, Tennessee at Murfreesboro, Malcolm McCune,

INVESTIGATION, RESEARCH AND TESTING

Since 1970

50TH ANNIVERSARY 1970 – 2020

Jill Denmark v. Jetson Electric Bikes, LLC and Amazon.com

Electrical Evaluation

Jetson Electric Bikes, LLC

Loss Location: 66 Mroz Road
Beaufort, South Carolina 29906

Date of Incident: September 27, 2017

Prepared for:

James P. Sullivan, Esquire

Howser, Newman & Besley, LLC

215 East Bay Street, Suite 303
Charleston, South Carolina 29401

Case No. 2020-CP-07-01847

S-E-A Matter No. 06.108931

Issue Date: May 25, 2021

Table of Contents

SOUTH CAROLINA LICENSED PROFESSIONAL ENGINEER No. 26056 SAMUEL G SUDLER III

SOUTH CAROLINA CERTIFICATE OF AUTHORIZATION SEA Ltd. No. 909

List of Figures

Acronyms, Abbreviations and Definitions

UL	Underwriters Laboratories
IEEE	Institute of Electrical and Electronics Engineers
ANSI	American National Standards Institute
AFCI	Arc-Fault Circuit Interrupter
IEC	International Electrotechnical Commission
NFPA	National Fire Protection Association
C.T.	Computer Tomography
JISC	Japanese Industrial Standards Committee
BMS	Battery Management System
S.O.C	State of Charge
OEM	Original Equipment Manufacturer
SEM	Scanning Electron Microscopy
EDS	Energy Dispersive Spectroscopy
USB	Universal Serial Bus
NSI	North Star Imaging
mAH	milli-Ampere-Hour
FMEA	Failure Mode and Effect Analysis
ETP	Eskra Technical Products
LIB	Lithium-Ion Battery
CID	Current Interrupting Device

I. Executive Summary

Matter Assignment

On October 28, 2020, McCoy, Leavitt, & Laskey, LLC requested SEA, Ltd. (S-E-A) to conduct an electrical evaluation and investigation in connection with the fire loss that occurred at the Denmark rental property on September 27, 2017, located in Beaufort, South Carolina. The investigation was assigned to S-E-A Senior Electrical Engineer Samuel G. Sudler III, P.E., IntPE, DFE, F.NSPE, C.F.E.I., C.V.F.I. as S-E-A Matter No. 06.108931. James P. Sullivan, Esquire of Howser, Newman & Besley, LLC represents the interests of Jetson Electric Bikes, LLC (Jetson).

Scope

Specifically, S-E-A was requested to conduct an electrical evaluation and investigation to determine, if possible, whether the cause of the fire loss was electrical in nature.

Methodology

The investigation and analysis of any fire-related incident is a complex and scientific endeavor. The methodology of such an endeavor, therefore, must include the comprehensive, objective, and accurate compilation and analysis of the available data. The methodology utilized by S-E-A in the investigation of this fire incident was *The Scientific Method*, in accordance with the requirements of NFPA 1033*, Standard for Professional Qualifications for Fire Investigator*, and the principles of NFPA 921*, Guide for Fire and Explosion*.

Conclusions

- **Based upon the joint evidence examinations, discovery documents, expert reports, reference material, UL Certification and Standards, ANSI Standards, and IEC Standards, it is the opinion of S-E-A that the subject hoverboard, found in the area of origin identified by CORE Engineering, was not the cause of the fire, and the unknown battery charger and its associated power cord cannot be eliminated as the cause of this fire**.
- **Based upon the evaluation of hundreds of similar battery cells, discovery documents, joint evidence examinations, expert reports, UL Certification and Standards, ANSI Standards, IEC Certification and Standards, and reference material, it is the opinion of**

S-E-A that even if the 18650 lithium-ion battery cells associated with the battery pack were manufactured by LG Chem, the battery cells were designed, functioned, and operated in accordance with all applicable standards, and that this fire was not caused by an internal short circuit that would have resulted in a thermal runaway failure within any of the recovered subject battery cells.

- **Based on the evidence examinations, discovery documents, expert reports, UL Certification and Standards, ANSI Standards, IEC Certification and Standards, and reference material, it is the opinion of S-E-A that if the area of origin was located under the bed as determined by CORE Engineering, then an electrical malfunction or failure associated with the unidentifiable power cord associated with an unknown battery charger cannot be eliminated as the cause of this fire.**
- **It is the opinion of S-E-A that the subject 18650 lithium-ion battery cell identified at 4H does not have enough power to cause this fire, which invalidates the ETP opinion that an internal short circuit in battery cell 4H caused this fire.**

Signatures

S-E-A and the undersigned hereby certify that the opinions and conclusions expressed herein are based upon the application of reliable principles and scientific methodologies to all of the facts known by S-E-A and the undersigned when this report was issued, as well as knowledge, skill, experience, training and/or education. Should additional information be discovered, S-E-A and the undersigned reserve the right to appropriately amend or augment these findings.

Prepared By:

Samuel G. Sudler III, P.E., IntPE, DFE, C.F.E.I.
Senior Project Engineer
State of South Carolina
License No. 26056

Technically Reviewed By:

Robert House

Robert S. House

II. Procedures

1. On April 1, 2021, a joint evidence examination was conducted at Safe Laboratories & Engineering Corp. (Safe Labs) located in Sanford, North Carlina by S-E-A Senior Electrical Engineer Samuel G. Sudler III, P.E., IntPE, DFE, C.F.E.I. on behalf of Jetson and other interested parties, at which time the following investigative tasks were performed:
   - The remains of electrical artifacts as well as the remains of the lithium-ion battery cells from the subject hoverboard were documented in the form of photographs, diagrams, and notes.
   - Radiograph (X-Ray) images of the circuit board later identified as the subject hoverboard balancing circuit board.
2. On April 2, 2021, a joint evidence examination was conducted at CORE Engineering Inc. (CORE Engineering) located in North Charleston, South Carolina by S-E-A Senior Electrical Engineer Samuel G. Sudler III, P.E., IntPE, DFE, C.F.E.I. on behalf of Jetson, and William B. Johnson, P.E. on behalf of the Jill Denmark, at which time the following investigative tasks were performed:
   - The artifacts from the room of origin that were collected and secured by CORE Engineering were examined in detail and were documented in the form of photographs, diagrams, and notes.
   - Radiograph (X-Ray) images and photographs from the scene examination and previous joint evidence examinations were provided by CORE Engineering.
3. Prior to the issuance of this report, various materials were researched, obtained, and/or reviewed, including but not limited to the following:
   - Discovery materials provided by Howser, Newman & Besley, LLC;
   - Report by Mike Eskra, CFEI from Eskra Technical Products, Inc. (ETP) dated April 19, 2021;
   - Report by William B. Johnson, P.E. from CORE Engineering dated April 23, 2021;
   - Computed Tomography (CT) Scan Data was obtained and reviewed.
   - Underwriters Laboratories, Inc. (UL) Certification No. BBCV2.MH19896 for LG Energy Solution, LTD using the basic standard UL 1642;
   - UL 1642 Safety Standard for “Lithium Batteries;”
   - UL 2054 Safety Standard for “Household and Commercial Batteries;”

- IEC 62133-2 Secondary cells and batteries containing alkaline and other non-acid electrolytes - Safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications - Part 2: Lithium Systems;
- International Classification Standard (ICS) 29.220.01 – National Standard of the People's Republic of China – GB/T 18287-2000 – General specification of lithium-ion battery for cellular phone;
- ICS 29.220.01 – National Standard of the People's Republic of China – GB/T 18287-2013 General specification of lithium-ion cells and batteries for mobile phone;
- Universal Serial Bus (USB) Specification, Revision 2.0, April 27, 2000;
- National Fire Protection Association (NFPA) 921, "Guide for Fire and Explosion Investigations," 2014 and 2017 Editions;
- Institute of Electrical and Electronics Engineers (IEEE) 1584™-2002 – IEEE Guide for Performing Arc Flash Hazard Calculations;
- Algebra and Trigonometry with Analytical Geometry, by Earl W. Swokowski and Jeffery A. Cole;
- Fundamental Engineering Reference Handbook by NCEES;
- Fundamentals of Thermodynamics, by Claus Borgnakke and Richard E. Sonntag;
- Heat Transfer: A Practical Approach, by Yunus A. Cengel;
- Kirk's Fire Investigation, Sixth Edition, by John D. DeHaan;
- Ignition Handbook, by Vytenis Babraukas;
- National Institute of Occupational Safety and Health (NIOSH) Pocket Guide to Chemical Hazards, by the Department of Health and Human Services – Center for Disease Control and Prevention (CDC);
- CRC Handbook of Chemistry and Physics, Editor-In-Chief David R. Lide, 91st Edition;
- Handbook of Batteries, Third Edition, by David Linden and Thomas B. Reddy;
- Battery Technology Handbook, Second Edition, Edited by H.A. Kiehne;
- Lithium-ion Batteries – Fundamentals and Applications, Edited by Yuping Wu;
- Lithium-Ion Batteries Hazard and Use Assessment (Springer Briefs in Fire), Celina Mikolajczak, Michael Kahn, Kevin White, and Richard Thomas Long;
- "Safe Lithium-Ion Battery Designs for Use, Transportation and Second Use," by Judy Jeevarajan, Ph.D.;

- National Aeronautical and Space Administration (NASA) Engineering and Safety Center Technical Bulletin No. 09-02, "Limitations of Internal Protective Devices in High-Voltage/High Capacity Batteries Using Lithium-Ion Cylindrical Commercial Cells;"
- Lithium-ion Rechargeable Batteries -Technical Handbook by Sony Electronics;
- ASC8513-2.5A, 400kHZ Switching Single Cell Li-Ion Battery Charger, Specification Sheet;
- Alpha & Omega Semiconductor – AO3407, 30V, P-Channel MOSFET, Specification Sheet;
- "Safety mechanisms in lithium-ion batteries," by P.G. Balakrishnan, R. Ramesh, T. Prem Kumar in Journal of Power Sources, 155 (2006) 401-414;
- "Thermal runaway caused fire and explosion of lithium-ion battery," by Qingsong Wang, Ping Ping, Xuejuan Zhao, Guanquan Chu, Jinhua Sun, Chunhua Chen in Journal of Power Sources, 208 (2012) 210-224;
- "Arc analysis to the CID of Li-Ion battery cells in high-current applications," by A. Augeard, T. Singo, P. Desprez, F. Perisse, S. Menecier and M. Abbaoui, at *2014 IEEE 60th Holm Conference on Electrical Contacts (Holm)*, New Orleans, LA, 2014, pp. 1-7;
- "Less Fire, More Power: The Secret to Safer Lithium-Ion Batteries," Weiyang Li and Yi Cui, in IEEE Spectrum, August 23, 2018;
- "Review of Specific Heat Capacity Determination of Lithium-Ion Battery," Yu Tang, Tao Li, and Ximing Cheng, at 10th International Conference on Applied Energy (ICAE2018), 22-25 August 20198, Ong Long, China;
- "Thermal Impedance Spectroscopy for Li-Ion Batteries with an IR Temperature Sensor System," Peter Keil, Katharina Rumpf, and Andreas Jossen, 27th Annual Electric Vehicle Symposium, November 17-20, 2013, Barcelona, Spain;
- "Thermal Properties of Lithium-Ion Battery Components," Hossein Maleki, Said Al Hallaj, J. Robert Selman, Ralph B. Dinwiddie, and H. Wang, Journal of The Electrochemical Society, 146(3) 947-954 (1999);
- William J. Meese and Robert W. Beausoliel, "Exploratory Study of Glowing Electrical Connections" National Bureau of Standards (NBS) Building Science Series 103, October 1977; and
- Bruce V. Ettling, "Glowing Connections" Fire Technology 18, No. 4 (1982): 344-349.

III. Discussion

Background

According to documentation, the Burton Fire District Incident Report, and discovery material, Jill Denmark purchased the residence at 215 East Bay Street in Charleston, South Carolina as a rental property in 2007. The property was eventually rented by Ms. Brown in 2015, as seen in **Figure 1**. On December 21, 2015 Ms. Brown purchased a Jetson Glyro hoverboard from Amazon.com that was used by her son. When the hoverboard was originally purchased her son used it frequently, but after getting his driver's license he used it less. Prior to the day of the fire, the hoverboard was last charged in August 2017, and there were no reported electrical issues with the hoverboard or the electrical structural wiring. On the night of the fire Ms. Brown was home with her children when she asked her 16-year-old son to clean his room. Her son plugged the hoverboard battery charger into the west outlet by the head of the bed and then connected it to the hoverboard, as seen in **Figure 2**. Ms. Brown's son then took a shower and about 45 minutes after charging the hoverboard Ms. Brown indicated she heard a pop and then a "whoosh" sound. She went from the kitchen to the hallway and looked in the bedroom and saw a fire under the bed in the area where the hoverboard was located. There was reportedly only the battery charger, the power cord for the battery charger, and the hoverboard under the bed. At 11:41 p.m., the Burton Fire District received an alarm of a fire at the Denmark rental property. Once the fire department had the fire under control and began their investigation, they found the hoverboard in three parts – left, right, and batteries. The battery cells were placed on the windowsill, as seen in **Figure 3**. According to the Burton Fire District Incident Report, the fire was caused by an electrical malfunction or failure involving a battery charger and rectifier.

Figure 1: CORE Engineering photograph of front entrance of the Denmark property.

Figure 2: CORE Engineering photograph showing bedroom facing the bed (Green Arrow) with outlet on west wall (Blue Arrow).

Figure 3: CORE Engineering photograph showing batteries on windowsill.

Joint Laboratory Examinations

Joint laboratory examinations of the retained artifacts were conducted on April 1, 2021 at Safe Labs located in Sanford, North Carolina and on April 2, 2021 at CORE Engineering located in North Charleston, South Carolina by S-E-A Senior Project Engineer Samuel G. Sudler, III, P.E., IntPE, DFE, F.NSPE, C.F.E.I. on behalf of Jetson and other interested parties. The artifacts were previously examined by all interested parties prior to S-E-A's involvement, so CORE Engineering shared its photographs with S-E-A to assist with collecting pertinent data. The examinations were conducted to determine if any of the artifacts exhibited evidence of a failure capable of causing the fire at the Denmark rental property.

All the artifacts (as shown in **Figure 4** and **Figure 5**) were examined in detail during the joint laboratory examinations. While all the items were examined, items of particular interest in the area of fire origin determined by CORE Engineering were as follows:

- The remains of the cylindrical 18650 battery cells
- The remains of the subject hoverboard
- A similar hoverboard

Figure 4: Remains of battery cells from subject hoverboard and other items recovered from the Denmark property.

Figure 5: Artifacts recovered from the Denmark property fire.

Examination of the remains of the cylindrical 18650 battery cells revealed designations of numeric-alpha identifiers. Several battery cells exhibited a vented event that ejected the electrolytic roll of the battery cells or dislodged the vent cap. Close examination of the battery cells revealed this ejection was consistent with the battery cells being attacked by fire, but with no evidence of arcing and shorting on the steel casing for any of the cells as seen in **Figure 6** through **Figure 12**.

Figure 6: CORE Engineering photographs showing the battery cell remains, the outlet, and the balancing board circuit board and wiring.

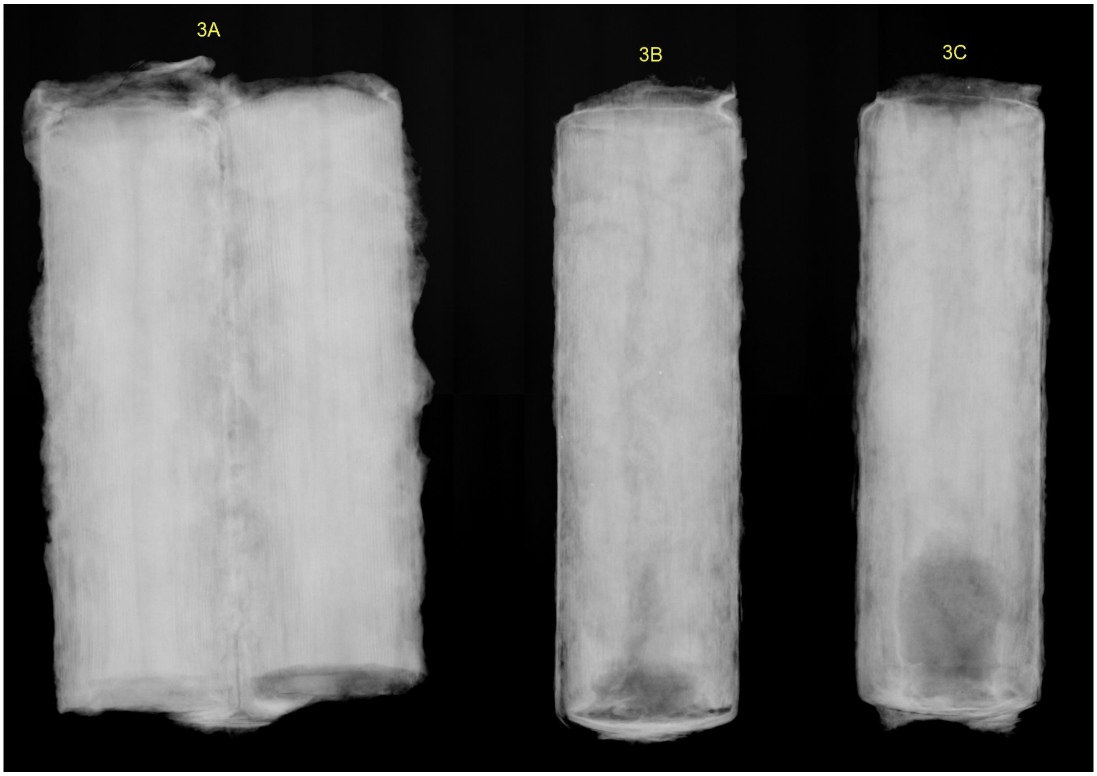


Figure 7: X-Ray images of Battery Cells 3A, 3B and 3C.

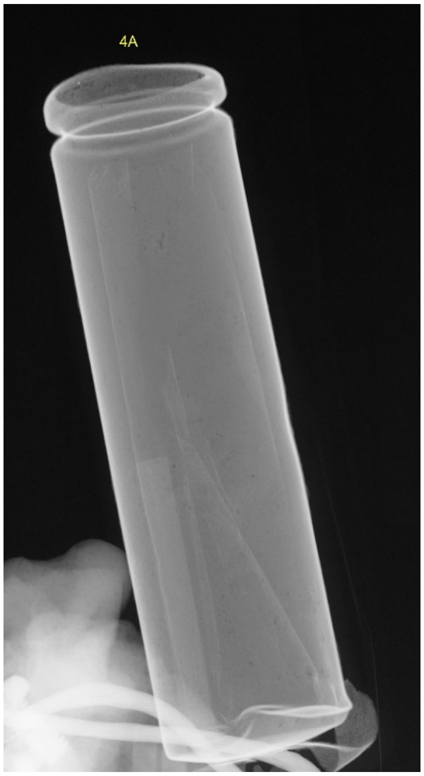


Figure 8: X-Ray image of Battery Cell 4A.

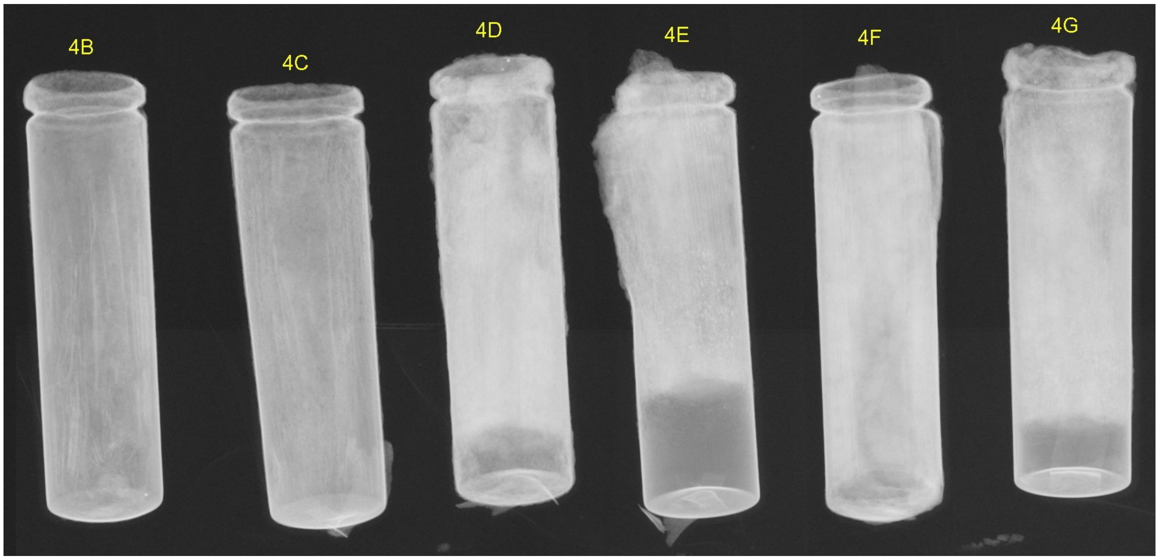


Figure 9: X-Ray image of Battery Cells 4B, 4C, 4D, 4E, 4F, and 4G.

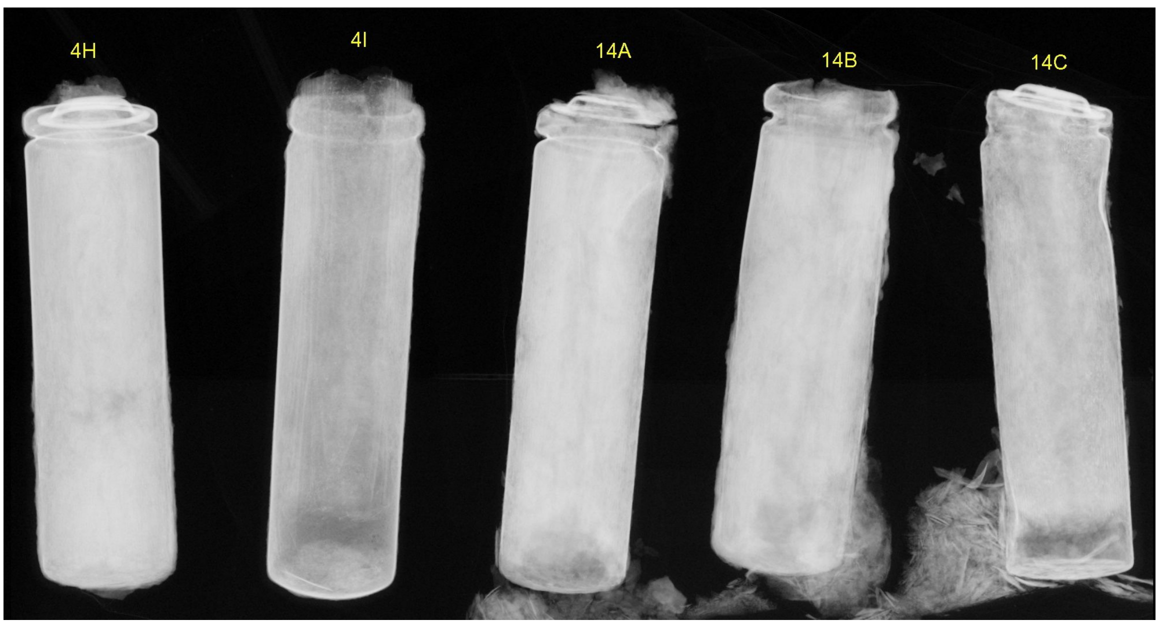


Figure 10: X-Ray image of Battery Cells 4H, 4I, 14A, 14B, and 14C.

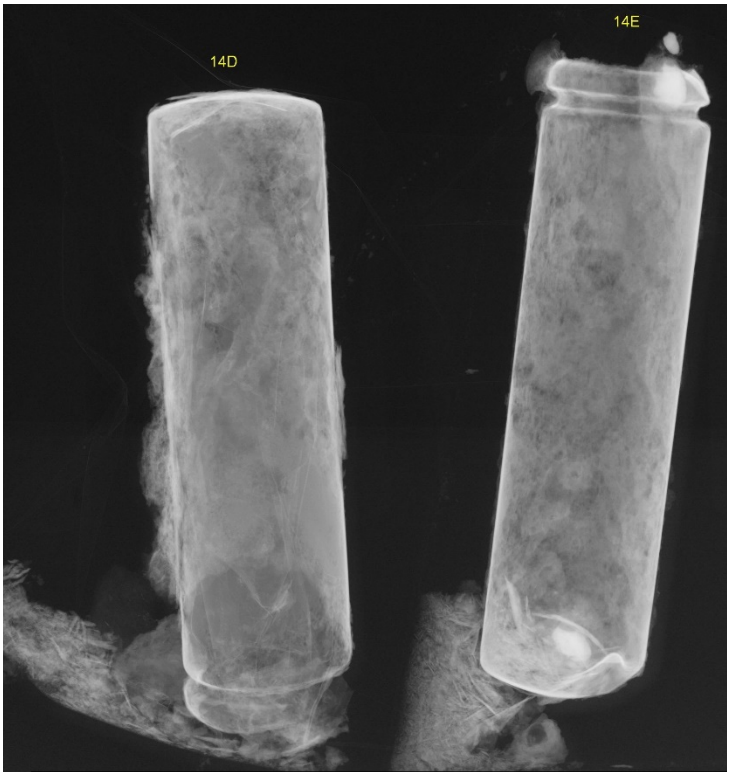


Figure 11: X-Ray image of Battery Cell 14D and 14E.

Figure 12: X-Ray image of Battery Cell 15A.

Examination of the artifacts continued with the remains of the subject hoverboard. It appears the hoverboard sustained heat damage from the exterior, as opposed to the interior, because the melted aluminum casing protected the batteries and circuitry for the hoverboard until the insulation for the battery cells was compromised, melting the portion of the casing where the battery pack was located, as shown in **Figure 13** through **Figure 15**. Examination of the hoverboard revealed that the main motor board and the two balancing boards were intact and exhibited no signs of electrical arcing and shorting in the form of melted copper as seen in **Figure 16** and **Figure 17**. Close examination of these X-Ray images revealed the soldered electronic components of the hoverboard control system were not melted and still intact. It is important to note that solder melts at 361℉ and aluminum melts at 1,200℉, so if the fire started in the interior of the hoverboard the solder would have melted, but it did not.

Figure 13: Remains of subject hoverboard.

Case23CV118 PL EX. 243B-087

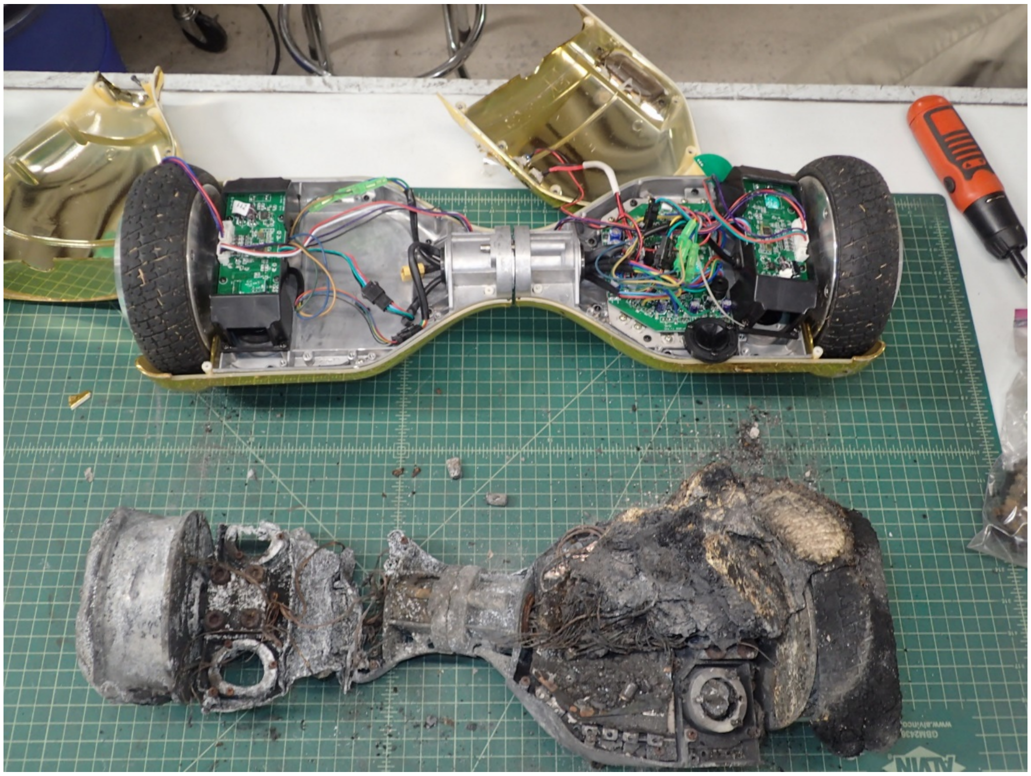


Figure 14: Subject hoverboard and similar hoverboard.

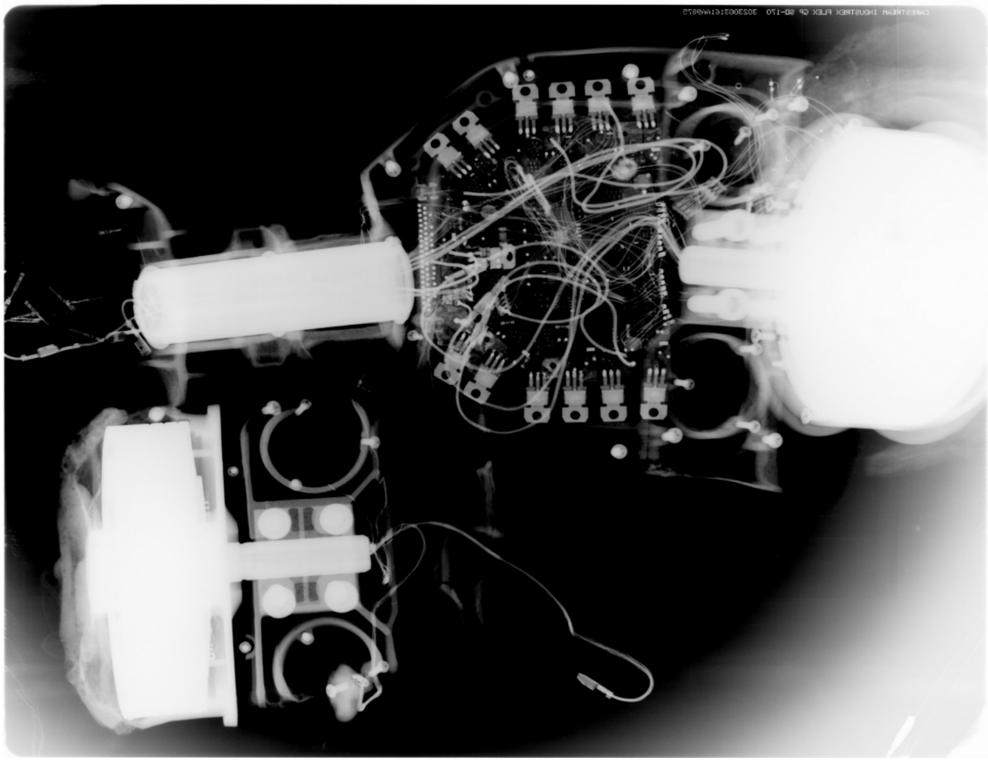


Figure 15: X-Ray of subject hoverboard and wiring.

Figure 16: X-Ray image of batteries and balancing board adjacent to battery pack for subject hoverboard.

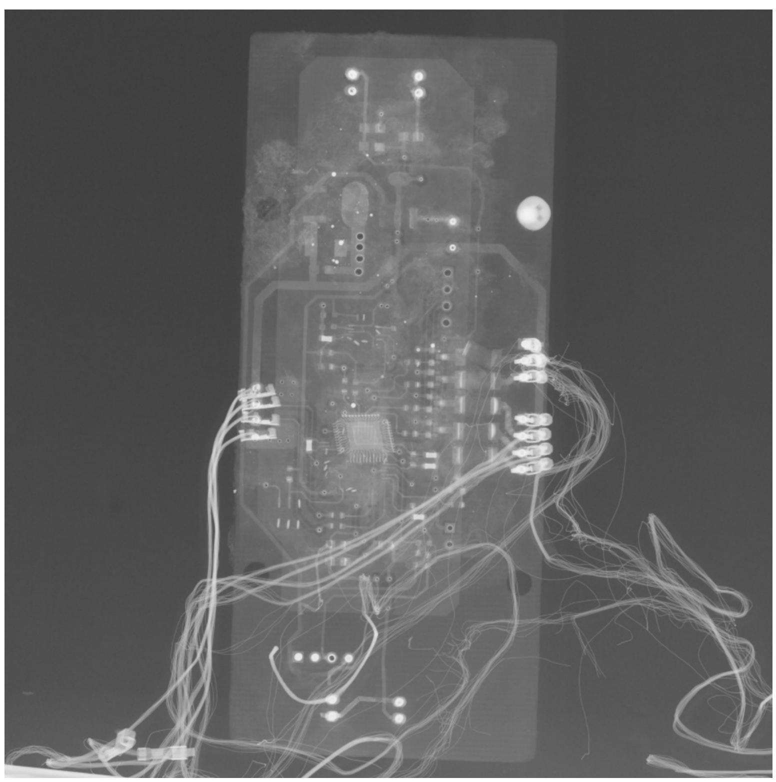


Figure 17: X-Ray of balancing board adjacent to battery pack for subject hoverboard.

Examination of the artifacts of interest continued with the electrical artifacts found in the area of fire origin as determined by CORE Engineering, as seen in **Figure 18**. Examination of the artifacts did not reveal evidence of the plug blades that would have been plugged into the outlet, or the power cord for the battery charger. Close examination of these artifacts revealed evidence of one board severely damaged that may have been related to the battery charger, as seen in **Figure 19**. However, due to the extensive damage of the board, it could not be eliminated as a cause of the fire.

Figure 18: Electrical artifacts from area of fire origin determined by CORE Engineering.

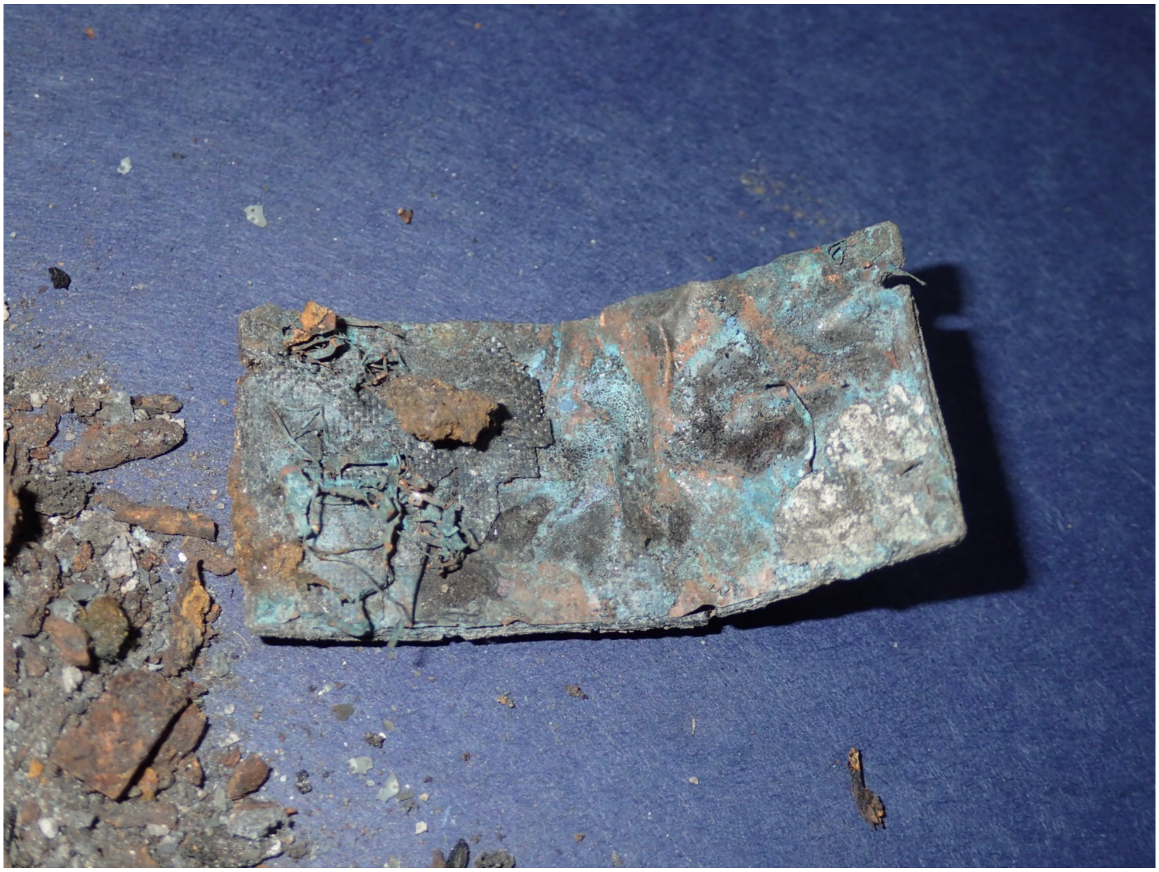


Figure 19: Close-up of unknown circuit board from area of origin determined by CORE Engineering.

Therefore, it is the opinion of S-E-A that the subject hoverboard, found in the area of origin identified by CORE Engineering, was not the cause of the fire, and the unknown battery charger and its associated power cord cannot be eliminated as the cause of this fire.

IV. Research and Investigation

Identification of the Lithium-Ion 18650 Battery Cell

Since all lithium-ion 18650 battery cells have the same dimensional characteristic of being 18-millimeters in diameter and 65.0-millimeters in length, identification of a lithium-ion cell is dependent on several characteristics. Identifying the cell is important to determine the electrical capacity of the battery cell, as well as knowing what testing of the battery cell would have been subjected to during its design and manufacturing. In the past, simply looking at the configuration of the positive tab with vent holes was a leading indicator of determining the manufacturer. Examination of the subject 18650 battery cells associated with the subject hoverboard revealed they had a four-hole positive tab vent, while all of the Samsung SDI 18650 battery cells have a three curved hole pattern on the positive tab, as seen in **Figure 20** through **Figure 22**.

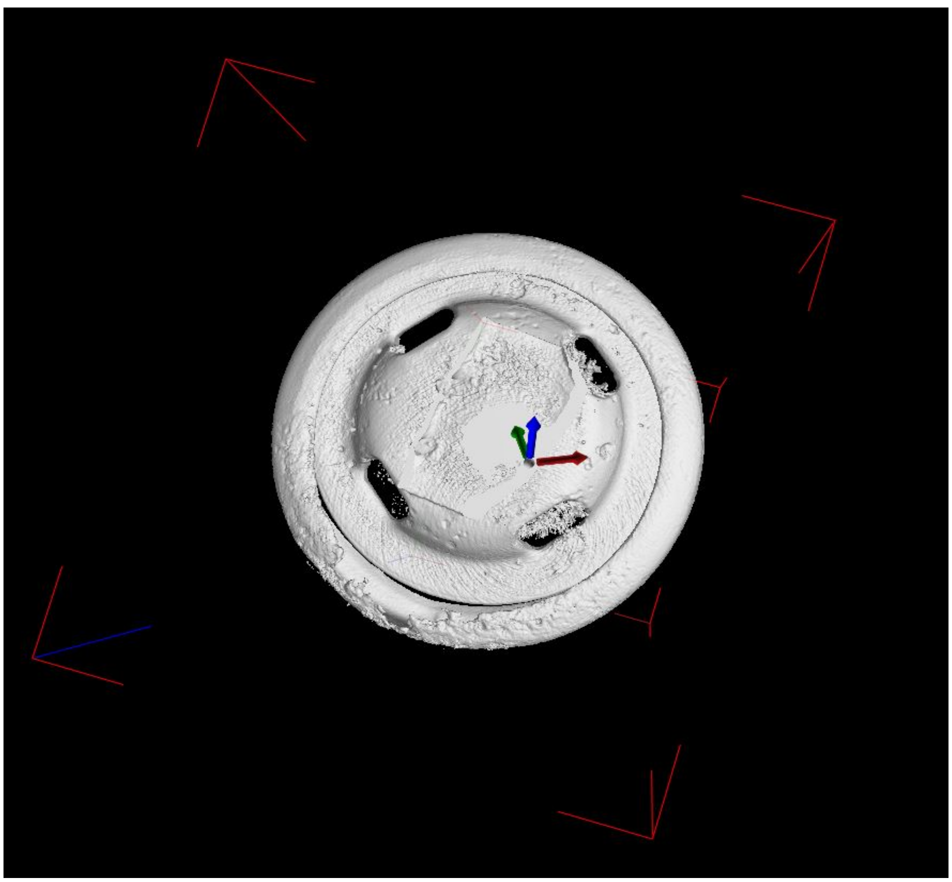


Figure 20: CT Scan image of positive vent cap for battery cell 4H.

Case23CV118 PL EX. 243B-092

Figure 21: Image of Samsung 22P battery with three-hole vent.

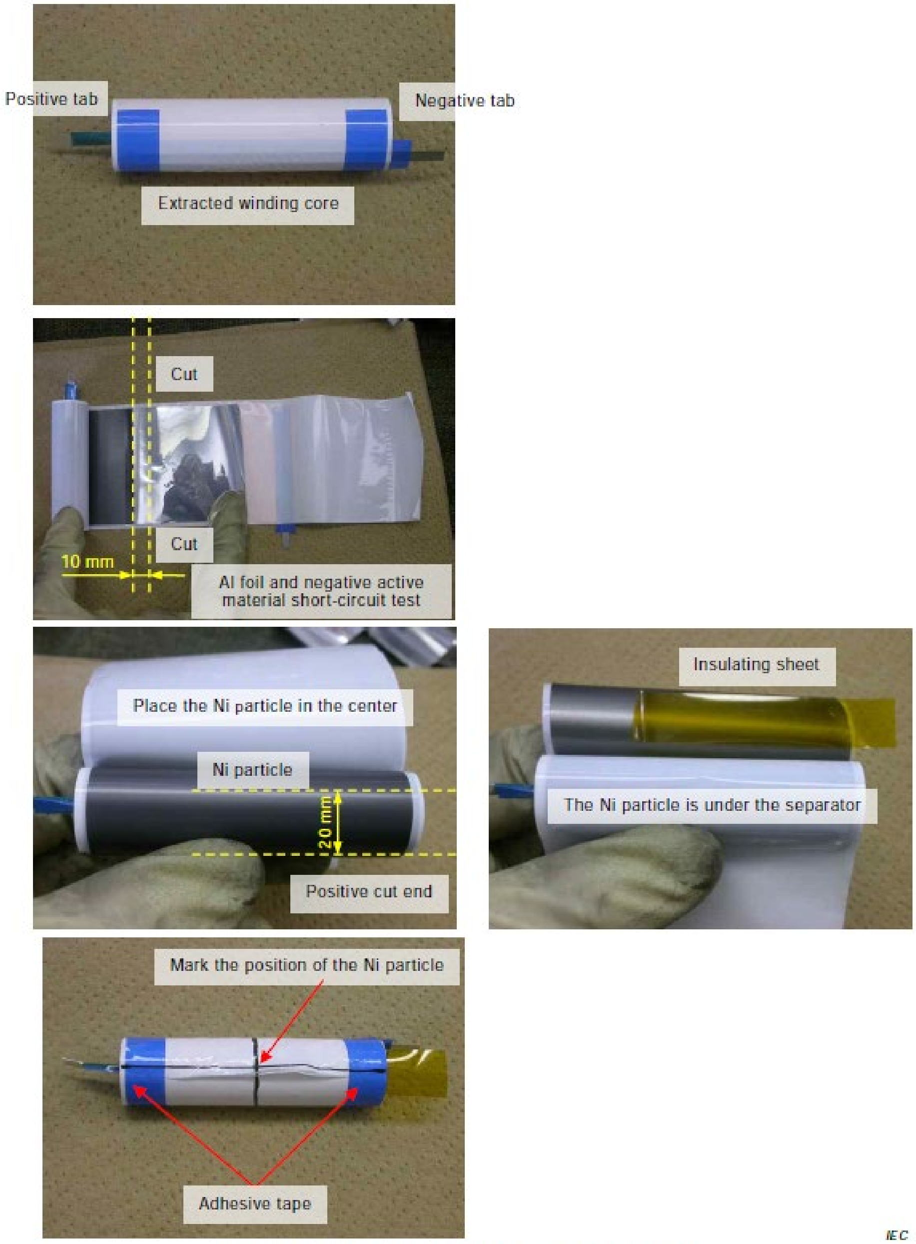
Figure 22: Image of LG Chem battery with four-hole positive tab vent.

Currently, there are a number of manufacturers that have the same four-hole positive tab vent hole configuration as the subject battery cells. For example, the Efan, Imren, and Efest have the same vent hole configuration even though other manufacturers have copied this design. However, according to the ETP Report the battery cell is possibly manufactured by LG Chem and not Samsung.

International Electrotechnical Commission (IEC) 62133 - 2 - Safety Requirements for Portable Sealed Secondary Cells - Part 2: Lithium Systems - Internal Short Circuit Test

Research on the IEC website confirms the LG Chem battery cells conformed to the IEC 62133-2 Safety Requirements for Portable Sealed Secondary Cells - Part 2: Lithium Systems. Review of this standard shows it is similar to the UL 1642 Standard for Lithium Batteries except that the IEC 62133-2 subjected the battery cell to an additional test - Design Evaluation - Forced internal short circuits in Section 7.3.9. The purpose of this particular test, and design evaluation, is to address any unlikely but potential manufacturing concerns with potential conductive material getting into the electrolytic roll, or if there is a concern with the separator used by the battery cell manufacturer for the electrolytic roll.

This test first involves opening the cylindrical cell, inserting a piece of nickel inside of the cell, as shown in **Figure 23,** and then putting it back together.



IEC

Figure A.6 – Disassembly of cylindrical cell

Figure 23: IEC internal short circuit test for a cylindrical cell.

The cell is then pressed using the test shown in **Figure 24**, by connecting a voltage and monitoring it for a 50-mV drop in voltage while pressing it with 800N of pressure for 30 seconds. The outcome of the test must not result in fire. LG Chem has been testing its cells, both

cylindrical and prismatic, since 2013 and passed the test that resulted in its IEC certification, as seen in **Figure 25.**

ii) Internal short-circuit

A Confirm that the winding core surface temperature is as defined in Table 5, and then start the test.

B The bottom surface of the moving part of the press equipment (i.e. pressing jig) is made of nitrile rubber or acrylic resin, which is put on the 10 mm × 10 mm stainless steel shaft. Details of the pressing jigs are shown in Figure 2. The nitrile rubber bottom surface is for a cylindrical cell test. For a prismatic cell test, 5 mm × 5 mm (2 mm thickness) acrylic resin is put on the nitrile rubber.

The fixture is moved down at a speed of 0,1 mm/s, monitoring the cell voltage. When a voltage drop caused by the internal short-circuit is detected, stop the descent immediately and keep the pressing jig in the position for 30 s, and then release the pressure. The voltage is monitored at a rate of more than 100 times per second. If the voltage drops more than 50 mV compared to the initial voltage, an internal short-circuit has been determined to have occurred. If the force of the press reaches 800 N for a cylindrical cell or 400 N for a prismatic cell before the 50 mV voltage drop, stop the descent immediately .

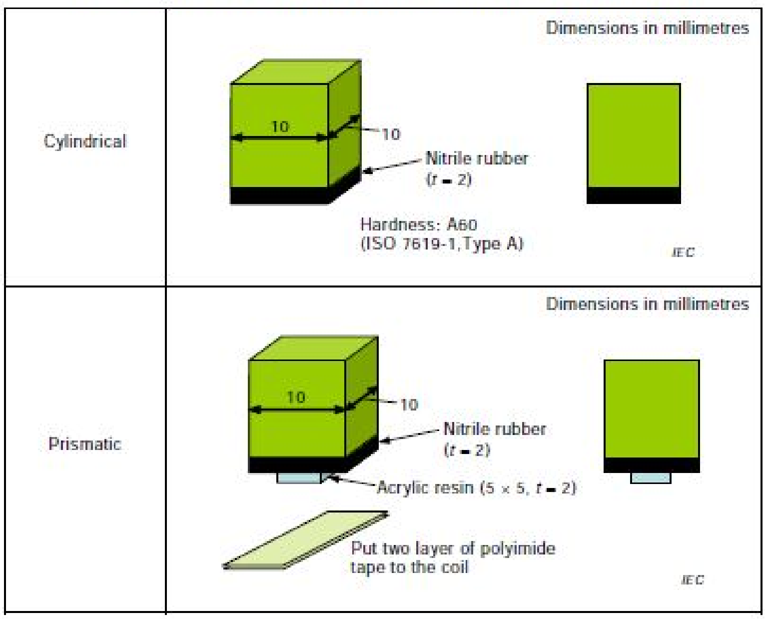


Figure 2 – Jig for pressing

c) Acceptance criteria

No fire. Record the force when an internal short-circuit occurs if there was no fire.

Figure 24: Second part of the IEC internal short circuit test.

Case23CV118 PL EX. 243B-096

IEC IECEE

Test Report issued under the responsibility of:

UL

TEST REPORT
IEC 62133, Second Edition
Secondary cells and batteries containing alkaline or other non-acid electrolytes – Safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications

Report Number. ....:	BA-4786867568-A-1
Date of issue ....:	2015-03-31
Total number of pages	26
Applicant's name ....:	LG CHEM, LTD
Address ....:	128 YEOUI-DAERO, YEONGDEUNGPO-GU SEOUL 150-721 REPUBLIC OF KOREA
Test specification:	
Standard ....:	IEC 62133: 2012 (Second Edition)
Test procedure ....:	CB Scheme
Non-standard test method.............:	N/A
Test Report Form No.......................:	IEC62133B
Test Report Form(s) Originator ....:	UL(Demko)
Master TRF ....:	Dated 2013-03

If this Test Report Form is used by non-IECEE members, the IECEE/IEC logo and the reference to the CB Scheme procedure shall be removed.

This report is not valid as a CB Test Report unless signed by an approved CB Testing Laboratory and appended to a CB Test Certificate issued by an NCB in accordance with IECEE 02.

Test item description ....:	Rechargeable Li-ion Cell
Trade Mark ....:	LG Chem
Manufacturer..................................:	LG CHEM, LTD/ RESEARCH PARK 188 MUNJIRO, YUSEONG-GU, DAEJEON, 305-738, REPUBLIC OF KOREA
Model/Type reference ....:	INR18650HG2 or HG2 / INR19/66
Ratings ....:	3.6Vdc, 3000mAh

Figure 25: LG Chem Test and Certification for IEC 62133-2.

It has been purported by ETP that the subject cell, identified as Cell 4H in this matter, sustained a manufacturing defect that could result in an internal short circuit that could then result in a failure that could cause a fire.

If there was an internal short circuit it would take time to develop, allowing the current interrupting device (CID) to activate and prevent any issue that could lead to a fire. For there to be an issue it must be an external short circuit capable of generating a current faster than the CID is able to respond to in time. However, because this is a closed loop electrical system, as seen in **Figure 26,** and the configuration of the battery pack does not allow an external short circuit to occur, as seen in **Figure 27**, the only way for the cells to sustain this type of damage is from an external thermal event such as a fire.

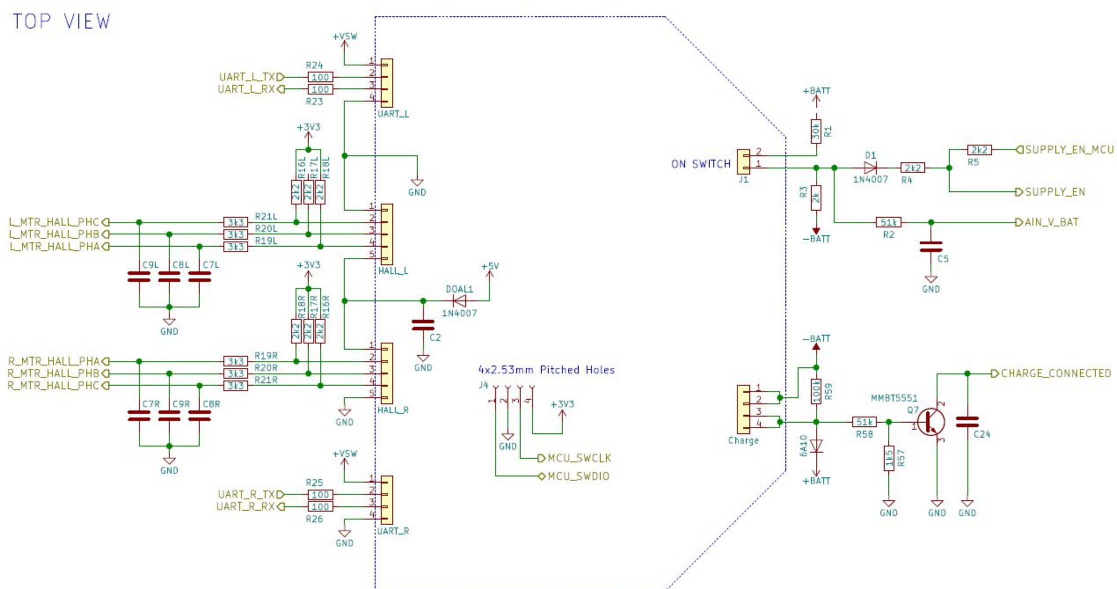


Figure 26: Closed loop electrical system for hoverboard.

Case23CV118 PL EX. 243B-098

Figure 27: CORE Engineering photograph of battery pack for a hoverboard.

Examination of a similar hoverboard revealed that the electronic circuit board, as well as the battery pack, were protected by an Aluminum enclosure. Close examination of the similar hoverboard also revealed that the battery cells were almost in contact with the balancing circuit board and the aluminum housing. According to NFPA 921, Aluminum melts at 1,220°F while identifiable temperatures in structural fires can reach temperatures of 1,900°F, as seen in **Figure 28**. It is important to note that physical examination and a review of the X-Rays associated with the balancing board revealed none of the electrical conductors, which melt at 1,981°F, exhibited visible evidence of electrical arcing and shorting in the form of melted copper, which would have occurred had the battery cells been the cause of this fire, as seen in **Figure 29**.

Table 6.2.8.2 Approximate Melting Temperatures of Common Materials

Material	Melting Temperatures °C	°F
Aluminum (alloys)[a]	566–650	1050–1200
Aluminum[b]	660	1220
Brass (red)[a]	996	1825
Brass (yellow)[a]	932	1710
Bronze (aluminum)[a]	982	1800
Cast iron (gray)[b]	1350–1400	2460–2550
Cast iron (white)[b]	1050–1100	1920–2010
Chromium[b]	1845	3350
Copper[b]	1082	1981
Fire brick (insulating)[b]	1638–1650	2980–3000
Glass[b]	593–1427	1100–2600
Gold[b]	1063	1945
Iron[b]	1540	2802
Lead[b]	327	621
Magnesium (AZ31B alloy)[a]	627	1160
Nickel[b]	1455	2651
Paraffin[b]	54	129
Plastics (thermo)		
ABS[d]	88–125	190–257
Acrylic[d]	90–105	194–221
Nylon[d]	176–265	349–509
Polyethylene[d]	122–135	251–275
Polystyrene[d]	120–160	248–320
Polyvinylchloride[d]	75–105	167–221
Platinum[b]	1773	3224
Porcelain[b]	1550	2820
Pot metal[e]	300–400	562–752
Quartz (SiO_2)[b]	1682–1700	3060–3090
Silver[b]	960	1760
Solder (63Sn/37Pb)[f]	183	361
Steel (carbon)[a]	1516	2760
Steel (stainless)[a]	1427	2600
Tin[b]	232	449
Wax (paraffin)[c]	49–75	120–167
White pot metal[e]	300–400	562–752
Zinc[b]	375	707

[a]From Lide, ed., *Handbook of Chemistry and Physics.*
[b]From Baumeister, Avallone, and Baumeister III, *Mark's Standard Handbook for Mechanical Engineers.*
[c]From NFPA *Fire Protection Guide to Hazardous Materials.*
[d]From McGraw-Hill, *Plastics Handbook.*
[e]From Gieck and Gieck, *Engineering Formulas.*
[f]From *Smithells Metals Reference Book*, 7th edition, Butterworth-Heinemann.

Figure 28: Melting temperatures of various metals and other items.

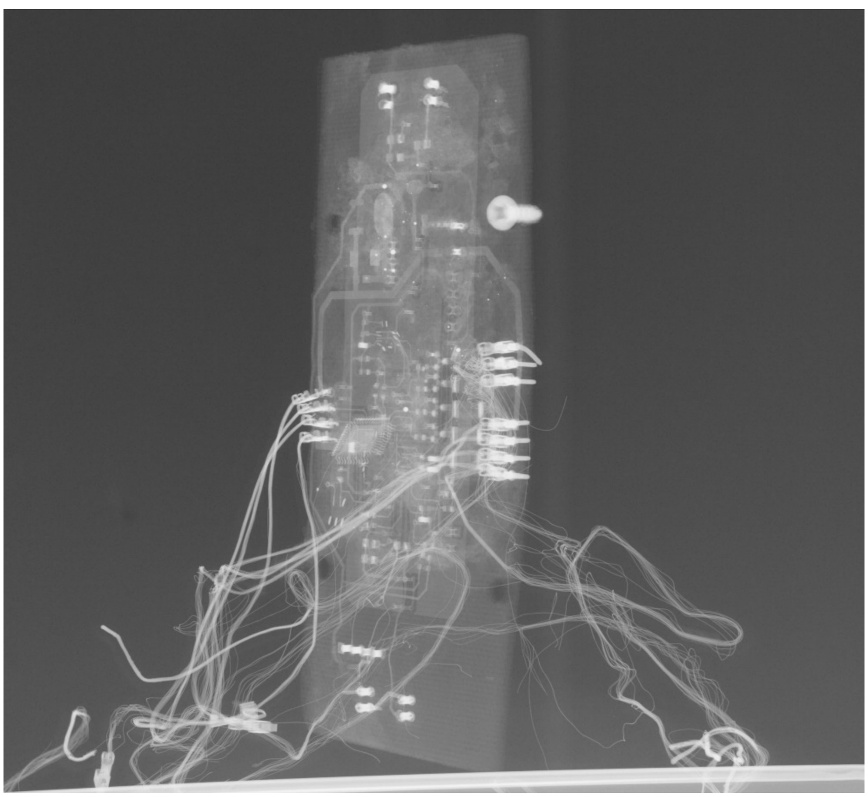


Figure 29: X-Ray of the balance board from subject hoverboard.

Therefore, it is the opinion of S-E-A that even if the 18650 lithium-ion battery cells associated with the battery pack were manufactured by LG Chem, the battery cells were designed, functioned, and operated in accordance with all applicable standards, and that this fire was not caused by an internal short circuit that would have resulted in a thermal runaway failure within any of the recovered subject battery cells.

Appliance Cords

According to the *Ignition Handbook,* the Consumer Product Safety Commission estimates that there are about 7,100 fires a year in U.S. residences originating from electrical cords or plugs. As a result, the Arc Fault Circuit Interrupter (AFCI) device was designed to attempt to reduce or eliminate fires caused by damaged power cords resulting in electrical arcing or shorting. Review of the scene photographs of the electrical panel that housed the circuit breakers for the property, as well as an examination of the circuit breaker that provided power to the electrical outlet, revealed the circuit breaker for this circuit was an AFCI, which was installed in 2005. According to NFPA literature an AFCI circuit breaker has moderate fire protection even if properly working, as seen in **Figure 30**.

Figure 30: Image from NFPA literature.

Kirk's Fire Investigation, as well as NFPA 921, indicates that a direct short circuit or ground fault creates a surge of current that melts the metal at the point of contact and causes a brief parting arc as a gap develops between the metal pieces. The arc quenches immediately but can throw particles of melted metal around capable of igniting paper or other combustible material. Examination of the artifacts from the area of origin determined by CORE Engineering revealed there was an unidentifiable charger for the hoverboard and an unknown power cord for the hoverboard battery charger.

Therefore, it is the opinion of S-E-A that if the area of origin was located under the bed as determined by CORE Engineering, then an electrical malfunction or failure associated with the unidentifiable power cord associated with an unknown battery charger cannot be eliminated as the cause of this fire.

Review and Evaluation of ETP Report related to the Subject Fire using the Scientific Method

After reviewing the ETP Report dated April 19, 2021, S-E-A again utilized the Scientific Method outlined in *National Fire Protection Association (NFPA) 921, "Guide for Fire and Explosion Investigations"* to evaluate the opinion proffered by ETP in their report, which are as follows:

- ETP Opinion – The fire at the Denmark rental property was caused by a failure of a battery identified as Item 4H.

The aforementioned hypothesis, or opinion, associated with the cause of this alleged battery fire incident will be evaluated using the Scientific Method, as suggested by the flow chart in NFPA 921 (**Figure 31**), utilizing all known and pertinent facts related to this matter, which include discovery documentation, joint evidence examinations of retained artifacts, that included the subject battery cells and other known information.

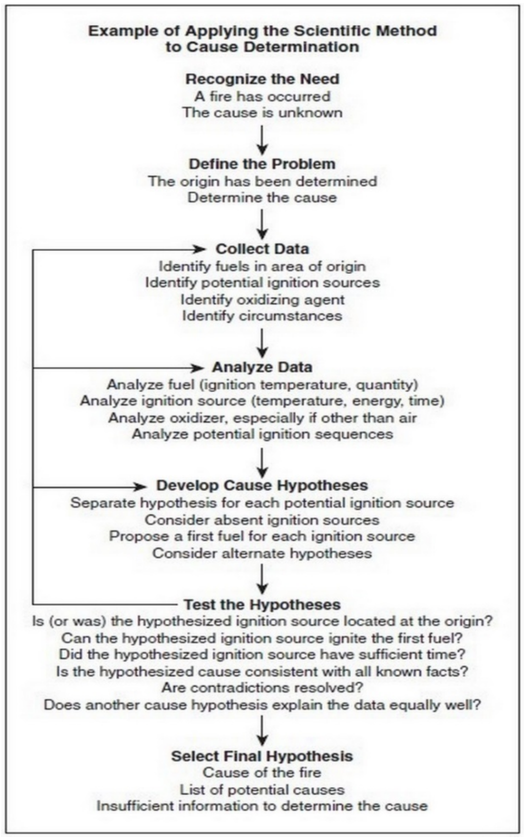


Figure 31: NFPA 921-199, shown as Figure 19.2.

Following the Scientific Method is used as a safeguard against two common issues that can lead to erroneous opinions, and those issues, as defined in NFPA 921, are as follows:

- Confirmation Bias - Different hypothesis may be compatible with the same data. When using the scientific method, testing of hypothesis should be designed to disprove a hypothesis (i.e., falsification of the hypothesis), rather than relying only on confirming data that support the hypothesis. Confirmation bias occurs when the investigator relies exclusively on data that supports the hypothesis and fails to look for, ignores, or dismisses contradictory or non-supporting data. The same data may support alternative and even opposing hypotheses. The failure to consider alternative or opposing hypotheses, or prematurely discounting seemingly contradictory data without appropriate analysis and testing can result in incorrect conclusions.
- Expectation Bias - Expectation bias is a well-established phenomenon that occurs in scientific analysis when investigator(s) reach a premature conclusion without having

examined or considered all of the relevant data. Instead of collecting and examining all of the data in a logical and unbiased manner to reach a scientifically reliable conclusion, the investigator(s) uses the premature determination to dictate investigative processes, analyses, and, ultimately, conclusions, in a way that is not scientifically valid. The introduction of expectation bias into the investigation results in the use of only data that supports this previously formed conclusion and often results in the misrepresentation and/or the discarding of data that does not support the original opinion.

ETP Opinion – The fire at the Denmark rental property was caused by a failure of a battery cell identified as Cell 4H.

This opinion proffered by ETP suggests that the fire at the Denmark rental property was caused by an internal failure of Cell 4H. It is important to note that Cell 4H was recovered outside of the area of origin determined by CORE Engineering. In addition, the battery cell for Cell 4H is rated at 3.7-VDC, 2.2Ah, and has a power rating of 8.14-Wh. According to ***<u>Heat Transfer: A Practical Guide</u>*** the amount of heat transfer is equal to Q=mCΔT, where mass is in kilograms and the specific heat for an 18650 lithium-ion battery cell is approximately 900 J/kg°C with Q being 8.14Wh and the mass being 0.044kg. Knowing the internal resistance of the battery cell is typically 50mΩ and P= 8.14Wh, current (I) one can calculate the battery fault current from $P=I^2R$ with I fault =√(P/R), which is 12.76-Ampers. With the discharge rate of 2.2Ah the fault current can be sustained for 10.34 minutes. Therefore, with Q=8.14WH or 29,304 Watts in one second, it would take at least 10 seconds to catch paper on fire. Paper ignites at approximately 220°, according to the *<u>Ignition Handbook.</u>* Therefore, the amount of power would be 2,930-Watts. Utilizing the Heat Transfer formula Tf = (Q/mC)+25°C, which give a temperature of 98.98°C. This is important because according to NFPA 921 you need at least 30-Watts of power to create a fire. Therefore, the battery only having had 8.13-Watts of power is not enough energy to cause the subject fire.

Therefore, it is the opinion of S-E-A that the subject 18650 lithium-ion battery cell identified at Cell 4H does not have enough power to cause this fire, which invalidates the ETP opinion that an internal short circuit in Battery Cell 4H caused this fire.

Appendices

Samuel G. Sudler III, P.E., IntPE, DFE, F.NSPE, C.F.E.I. Credentials

1. Samuel G. Sudler III, P.E., IntPE, DFE, F.NSPE, C.F.E.I. CV
2. Samuel G. Sudler III, P.E., IntPE, DFE, F.NSPE, C.F.E.I. Testimony Log
3. Samuel G. Sudler III, P.E., IntPE, DFE, F.NSPE, C.F.E.I. Billable Rate Disclosure

List of Referenced Material

1. American National Standards Institute (ANSI)/National Fire Protection Association (NFPA) 70E – Standard for Electrical Safety Requirements for Employee Workplaces, 2015 Edition
2. UL 1642 Safety Standard for "Lithium Batteries"
3. UL 2054 Safety Standard for "Household and Commercial Batteries"
4. IEC 62133-2 Secondary cells and batteries containing alkaline and other non-acid electrolytes - Safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications - Part 2: Lithium Systems
5. International Classification Standard (ICS) 29.220.01 – National Standard of the People's Republic of China – GB/T 18287-2000 – General specification of lithium-ion battery for cellular phone
6. ICS 29.220.01 – National Standard of the People's Republic of China – GB/T 18287-2013 General specification of lithium-ion cells and batteries for mobile phone.
7. Universal Serial Bus (USB) Specification, Revision 2.0, April 27, 2000
8. National Fire Protection Association (NFPA) 921, "Guide for Fire and Explosion Investigations," 2014 and 2017 Editions

Rebuttal Report

Fire at Jill Demark Property

Location of Loss: 66 Mroz Road, Beaufort, SC

Date of Loss: September 26, 2017

Claim/Reference Number: 9.20-cv-3706-MBS

Prepared For

Mr. Jack McKenzie

McDonald, McKenzie, Rubin, Miller & Lybrand, LLP

SOUTH CAROLINA
PROFESSIONAL ENGINEER
LICENSED
No. 28866
JOHN P. CAVAROC

June 25, 2021

Date

AUTHORED BY: John Cavaroc Ph.D., P.E.

SAFE LABS

SAFE Laboratories and Engineering Corp
5901 Elwin Buchanan Drive, Sanford, NC 27330
Firm License Number: **C-3696**

Table of Contents

I. INTRODUCTION

On September 26, 2017 a fire occurred at 66 Mroz Road, Beaufort, SC, a rental property owned by Ms. Jill Demark and occupied by Ms. Kathy Brown. The dwelling was insured by State Farm Insurance (State Farm) at the time of the fire. State Farm investigated the fire, which resulted in litigation between State Farm and other interested parties. The subject of the litigation is a hoverboard that was owned by Ms. Brown. On May 26, 2021, Mr. Jack McKenzie, Partner with the McDonald, McKenzie, Rubin, Miller & Lybrand, LLP law firm assigned me, Dr. John Cavaroc, Ph.D., P.E., Electrical Engineer with SAFE Laboratories and Engineering Corp. (SAFE Labs) to analyze an opinion offered by one of the interested parties.

II. BACKGROUND

After the fire was reported to State Farm, Mr. Brian Yarborough with State Farm assigned Mr. Bill Johnson, President of CORE Engineering Corp. to investigate the origin and the cause of the fire. Mr. Johnson determined the fire originated in a bedroom at or near a hoverboard that was located under a bed. Mr. Johnson subsequently assigned Mr. Mike Eskra with Eskra Technical Products, Inc. to analyze the battery remnants associated with the hoverboard. After doing so, Mr. Eskra determined the fire was caused by an internal short circuit associated with the hoverboard battery cell designated 4H. Mr. Eskra issued a report describing his opinions on April 19, 2021. On April 23, 2021 Mr. Johnson issued a report describing his opinions, and incorporating Mr.Eskra's opinions. On May 25, 2021, Mr. Samuel Sudler III, P.E., Senior Project Engineer with SEA issued a report disputing Mr. Eskra's determination. Mr. Sudler's report was issued Mr. James Sullivan of Howser, Newman & Besley, LLC, who represents Jetson Electric Bikes, LLC, the amazon vendor that supplied the hoverboard to Ms. Brown. Mr. Sudler and SEA opine

> *…that the subject 18650 lithium-ion battery cell identified at Cell 4H does not have enough power to cause this fire, which invalidates the ETP opinion that an internal short circuit in Battery Cell 4H caused this fire.*

Mr. McKenzie assigned me to analyze this opinion.

III. INVESTIGATION

The methodology used in this analysis generally follows the scientific method described in NFPA 921 *Guide for Fire and Explosion Investigations.*

Upon receiving the assignment, I obtained the reports of Mr. Johnson, Mr. Eskra and Mr. Sudler. I also requested and received Mr. Johnson's file. I reviewed his photographs from the site and subsequent laboratory examinations and discussed the circumstances of the incident with him. Mr. Johnson advised me that he had acquired an exemplar hover board and this hover board was transferred to SAFE Labs on June 23, 2021. I inspected and analyzed this hover board on June 24, 2021.

Prior to receiving Mr. Johnson's exemplar hover board, I located a similar hover board in the SAFE Labs exemplar inventory. I inspected and analyzed this hoverboard prior to receiving Mr. Johnson's hoverboard. Cells from the battery packs associated with both exemplar hover boards were subjected to CT scans and testing at SAFE Labs.

Additional employees of SAFE Labs and I conducted research and a literature review of 18650 lithium-ion batteries, the type of battery cell used in the exemplar and subject hover boards.

Prior to my involvement in this matter, Mr. Johnson had contracted with SAFE Labs to perform CT scans and x-rays of the subject cells, as outlined in his report. I had no involvement in that work and had not analyzed those CT scans or x-ray images prior to receiving this assignment.

The analysis in this report is based on information available as of this writing. Should new information become available, the analysis and conclusions may be supplemented or modified. The analysis and conclusions state the probable circumstances of the incident to a reasonable degree of engineering certainty.

IV. LITERATURE REVIEW AND RESEARCH

The 2021 edition of NFPA 921 recognizes that Lithium Ion batteries, such as the ones used in the subject hoverboard, are competent ignition sources and can cause fires. This is found in section 9.13, Lithium Ion Batteries, which is quoted below.

9.13 Lithium Ion Batteries.
Lithium ion batteries are commonly used in portable appliances, toys, portable electronics, and standby power applications. Several different chemistries are used with different inherent characteristics, but the investigator should be aware of certain characteristics that are common to most types:
(1) All lithium ion batteries can overheat and ignite if overcharged, undercharged, exposed to excessive heat or cold, flooded, short circuited, or physically damaged.
(2) If a lithium ion battery does fail catastrophically, copious amounts of flammable and/or poisonous gases may be emitted, some of which may be lighter or heavier than air.
(3) Lithium ion batteries typically exhibit remarkably low internal electrical resistance that can result in catastrophically high short-circuit currents if the output leads are short circuited.
(4) Most lithium ion battery packs or battery banks can provide remarkable amounts of energy to an ignition source at the fire origin point.

Lithium-ion batteries (LIB) have continually increased in popularity since their inception. In large part, this is due to their superior energy density, meaning they can store a large amount of energy in a small package. LIB applicability ranges from tiny sensors to large electric vehicles and electric utility grid-tied energy storage systems. Although LIB's have many beneficial qualities and applications, there remains a serious hazard associated with them. It has been well documented that LIBs can present a significant fire and explosion risk. Due to the number of fires caused by LIBs, many organizations and government agencies have created battery safety standards specifically for these batteries. Unfortunately, with rapidly advancing technology and new demands on LIBs, safety standards cannot keep up with, or guarantee the safety of LIBs in practical applications. The safety standards are constantly being updated [1].

A. Thermal Runaway

The primary LIB hazard resulting in fires or explosions is a condition known as thermal runaway. During thermal runaway, a LIB cell can experience an extreme temperature rise, ejection of gas and other internal components, combustion, and fire and/or explosion. [2,3,7-9,18,22,24,29].

Thermal runaway is typically caused by an internal short circuit, which can be triggered by physical/mechanical, electrical or thermal conditions. An internal short circuit is thought to be the most common precursor of thermal runaway [3]. This presents a serious threat considering some 18650s can have a sizeable discharge current. LG and Samsung both make cells that offer a continuous discharge current of 25-35A [4,5]. Another vendor lists the short circuit current of these cells in the 200A range [6].

There are multiple stages of reactions that a cell goes through leading up to, and during, a thermal runaway event. In a paper reviewing 18650s manufactured by Panasonic and LG, the exothermic reactions of thermal runaway were determined to progress in five stages [7].

1. Stage one is a state of little to no cell self-heating.
2. Stage two is entered when the self-heating can be detected but has not progressed to a state of irreversibility. This state has been caused by the initial decomposition of the solid electrolyte interface (SEI) layer and can start as low as 60 degrees C. The SEI layer protects the graphite anode from the electrolyte. If the SEI decomposes, the intercalated lithium in the graphite anode electrode can contact the electrolyte again and regenerate the SEI layer.
3. Stage three starts the last reversible self-heating stage. This is where the separator will begin melting, reducing the isolation between the anode and cathode. This leads to what is referred to as a soft internal short circuit. During this stage there is a sharp increase in temperature and oxygen can accumulate in the cell. At this point the cell's pressure may raise to a point of an initial venting.
4. Stage four begins the final and more severe venting where a "hard" internal short circuit has formed. This leads to accelerated heat buildup which leads to combustion as soon as there is enough oxygen. In this stage the self-heating is so fast it is irreversible, the pressure builds rapidly, and venting can eject cell components and cause fire and chemical explosions.
5. Stage five is the period in which the reactions have already occurred and what's left of the cell cools down.

According to this research, it is the soft/hard internal shorting that is often the main reason thermal runaway occurs. It was found that the LG cells began self-heating at a lower temperature than the Panasonic cells due to the chemistry of the cell - NMC811 vs NCA technology. The LG cells also had a more violent final venting stage due to the stronger gassing resulting from the positive electrode decomposition [7].

Another paper analyzing 18650s exposed to external heat sources simplified the description of the above process with four stages [8]:

1. Stage one is described as a gradual expansion of the cell leading to the safety valve venting small amounts of gasses. In their experiment this was recorded over 40 seconds, 42 seconds, 52seconds and 58 seconds for 100%, 90%, 80% and 70% state of charge (SOC), respectively.
2. Stage two is described as considerable amounts of gases being released from the cell and mixing with oxygen, forming a flammable mixture around the battery surface, and igniting. The point of ignition occurred at 43 seconds, 45 seconds, 60 seconds, and 65 seconds for 100%, 90%, 80%, and 70% SOC, respectively.

3. Stage three involves a violent explosion with a second jet of fire seen where the cell cap separated from the cell and all of the electrolyte and remaining vapors are ignited. This can last for several seconds.
4. Stage four involves the reactions quickly ending and the fire extinguishing.

Whether the thermal runaway condition is described in 4 or 5 stages, the result is the same - a fire.

Once one cell has failed and gone into thermal runaway, it can be expected that thermal failure will propagate, or cascade through a battery pack [2,3,13,26] and the propagation speed with which this occurs is linearly proportional with SOC [3].

Additional research has shown there can be a second combustion event, which is much more violent than the first, and this second event typically occurs with the ejection of a flame[3,9].

NASA has conducted tests where 18650 cells were forced to failure and were found to have lateral jet flames appearing from a cell's side wall during thermal runaway [10].

B. State of Charge

State of charge is the amount of energy that a LIB is storing at any given instant. It is usually expressed as a percentage of its maximum rating. A LIB at 100% SOC is storing its maximum rated amount of energy. An LIB at 0% SOC is not storing any useable energy. As the LIB is charged, the SOC will increase from 0% to 100%. While charging, it does not take long for a cell/battery to reach over 50% SOC due to LIBs fast charge rate, and it can reach 80% SOC in less than 20 minutes of charging [7].

The above work also found that 70, 80 and 90% SOCs had two peak heat release rates whereas the fully charged cell only had one. This is thought to be due to the more severe and rapid reaction at 100% SOC during thermal runaway [8].

The cell's SOC has been shown to be one of the most significant factors in contributing to the severity of the thermal runaway reactions. Higher SOC will generally have increasingly violent reactions and cells below 40-50% SOC may have little or no reactions or thermal runaway events [3,8,11,13,22].

One way to force an 18650 cell into thermal runaway is to create a short circuit by mechanically shorting the anode and cathode inside the cell. This can be accomplished by puncturing the cell

housing and the outermost cell layers, forcing a short between the anode and cathode. During a puncture test study of Samsung 2.5Ah 18650 cells with a 20A discharge rate, a nail was used to puncture the cells, creating an internal short circuit. It was found that an SOC of 50%, an internal short circuit could lead to thermal runaway [11]At the highest SOC, the initial short circuit current is at its peak and the critical temperature for thermal runaway is at its lowest. As temperature increases, the rate of electrochemical reactions and transport also increases, which coincides with lower internal resistance [12]The higher SOC reactions are also evident in mass loss, where a cell with higher SOC will lose more mass during thermal runaway than a cell with lower SOC[13]. With low state of charge, the cell is more stable because there is a lower reaction potential and with lower SOC, there is also a delay in the formation of internal short circuits.

C. Ignition of Nearby Combustibles

Another way to force an 18650 cell into thermal runaway is by environmental heating, or thermal abuse. This will damage the separator separating the anode and cathode inside the cell and allow a short circuit to develop. In practice, 18650 cells can be exposed to environmental heating from a neighboring cell that has entered thermal runway, which can sometimes lead to a cascading failure throughout the entire battery pack. In practice, environmental heating can also originate from high resistance electrical connections [2]In the lab, environmental heating can be used to force an 18650 cell into thermal runway.

In a forensic characterization of failed single-cell Samsung 18650s (2.5Ah), it was noted that items such as bedding and upholstered furniture materials are often the first items ignited by a heat source. In this study, the 18650 cells were forced into thermal runaway with environmental heating by wrapping them with heater wire and then placing them in a large tube. The cell started at 100% SOC and was heated until it entered the stage of cell venting. At that point, there was a gas jet released and sparks from the vent orifice ignited the gas, starting a chain of combustion events. There were two distinguishable types of venting behaviors, a jet flame and an explosive release. With the jet flame, there was a steady release of gas and subsequent flames, but the cell was left intact. In the explosive case, the gases were released far quicker and more intensely, with the internal jelly roll (internal cell contents consisting of current collectors, anode, cathode and separator) being pushed out, and often seen burning outside of the test tube. After these events, the cell housing was found empty, and, more alarming, the cell was not found in the original

location. A noticeable pattern emerged. These explosive events were occurring more frequently in an inert environment where the tube had nitrogen flowing through it, reducing the oxygen level to 0.02%. Of the 32 cells that were tested, six were in air and 26 were in the inert environment. Of the 26 tests in an inert environment, nine resulted in explosions. In the six air tests, only one resulted in an explosion. During the air tests, when the main venting event occurred, small flames were seen which lasted for several seconds. From these tests, they concluded that in partially enclosed spaces with limited oxygen/air supply, the battery venting process could still produce heat fluxes and temperatures sufficient to cause secondary ignition [13]

In the same study, additional testing was conducted where the cell was placed vertically on a horizontal cushion and with a vertical cushion secured against it. During the 100% SOC test, the vertical cushion ignited immediately followed by the horizontal cushion beneath it. The horizontal cushion was ignited by the propagating flame at the bottom of the cell. At 70% SOC, the cell only produced sparks during thermal runaway and the cushion did not ignite at first; however, after a short period of time, a small flame emerged from the cap and the flame spread to the cushion. The vertical cushion was no longer used due to the ease at which it ignited. At 50% SOC, the cell only vented gases. It did not ignite the cushion and only caused smoldering reactions. In a few cases, the smoldering led to flames and subsequent fire. At 30% SOC, the cushion melted but never ignited [13]

This paper also demonstrated propagation effects because the cell that was triggered then propagated, or cascaded, to the other cells and this occurred in the same sequence each time. The sequence depended on where the cell was located within the pack, in this case a laptop battery pack made of 18650s. They measured heat fluxes of 4-8 kW/m^2 at about 0.5 meters away from the laptop [13]

Other research analyzed the amount of energy that is released from a cell during thermal runaway. Using a specific heat of 700 J/kg°C, and a measured heat increase of 523°C, they found the energy released to be 15.6kJ or 4.33Wh. This equates to roughly half of the cell's available electrical energy at 8.64Wh. During these tests, "squirting" out burning electrolyte just prior to entering thermal runaway was also observed [28].

D. Internal Safety Devices

Over the years, battery manufacturers have improved cell safety design for 18650 cells to include Positive Temperature Coefficient (PTC) thermistors, safety vents, and Current Interrupt Devices (CID). The PTC functions by reducing current as its resistance increases due to heating. However, it was noted that a PTC cannot prevent an internal short. As such, a PTC alone might not be sufficient for preventing thermal runaway propagation in a battery pack. Likewise, safety vents might not be sufficient for preventing thermal runaway. With safety vents, the gases must be released quickly and early, and some fires and explosions have resulted from these vents becoming clogged or just having a poor design[14] Finally, the presence of a CID also might not be sufficient to prevent thermal runaway. In some cases, it was observed that a CID opening with a battery voltage above around 19-20 V can generate and maintain an arc that can trigger thermal runaway, or worse yet, an electrolyte fire [15].

During fault conditions and thermal runaway, the pressure increase can occur so fast that safety features (CID, PTC, vents) of even the most advanced 18650 cell designs may not prevent catastrophic failure. One study examined the reliability of these safety devices in 18650 across Samsung (2.5Ah), Panasonic (3.4Ah), Sanyo (2.6Ah) and LG (2.2 & 2.6Ah) cells. These cells were forced to failure and it was common to find their pressure relief was hindered, causing the cell to rupture and release hot projectiles and molten materials. The thermal runaway propagated throughout the pack in less than two seconds with the initial cell rupturing in less than 0.01 seconds. This research recorded the induced failure events and demonstrated the speed at which the process unfolded. The Samsung, LG and Panasonic cells all burst due to vent clogging or inadequate flow capacity through the vent. Some heated projectiles traveled several meters and this posed significant fire risk anytime ignitable materials were located within that distance [9]

E. Recalls and Other Documentation

In addition to the research that has been regarding the fire hazards associated with LIBs, there have been numerous recalls and press releases documenting the threat:

1. Self-Balancing Scooters/Hoverboards Recalled by 10 Firms Due to Fire Hazard [16]
2. In Dec 2020 the LG RESU10H home energy storage system was recalled for 5 fires [17]

3. Consumer Product Safety Commission released a warning Jan. 2021 stating that 18650s can cause serious injury or death. It noted that when these cells are used individually outside of a battery pack or installed in a device, they are hazardous when handled, transported, stored, charged or used to power device. Specifically, they present danger when shorted as this can cause the cell to overheat, trigger thermal runaway and then ignite and "forcibly expel burning contents, resulting in fires, explosions, serious injuries and even death" [18]
4. LG Chem released a safety warning regarding the use of their cylindrical lithium-ion cells in e-cigarettes as it could result in "disfiguring fire/explosion injury" [19]
5. LG Chem established a website to warn of the risks associated with handling bare individual 18650 cells [20]
6. HP Expanded their Recall on laptop batteries due to fire [21]
7. There have been a number of documented Tesla fires [22]
8. FEMA report on E-Cigarette fires and explosions reported 66% of the fires documented ignited nearby items [30]

Unfortunately, the above recalls were reactive and not proactive, so actual fires or explosions caused from the LIBs prompted the recalls.

Another 18650 LIB application with numerous reports of fires and explosions is e-cigarettes. Many of these devices are powered by 18650 LIBs and can present a fire hazard. One case discussed the explosion from a single cell lithium-ion battery while being stored in the user's pocket. The battery was charged overnight and was not found to be damaged or over-heated. While in the user's pocket, the cell exploded without warning and then vented flames. A similar situation was identified involving an individual cell being carried in a user's pocket and the cell exploded with flames [23].

Another paper noted 10 cases where individuals were burned by e-cigarette LIBs. In these cases, nine out of ten resulted in thermal injury with the tenth also having injury from a blast. Seven events occurred with the battery self-combusting in the pocket or lap; one resulted in the vaporizer exploding, one exploded while in use, and one reported ignition of the lighter after an accident. This paper also notes a FEMA report highlighting several e-cigarette explosions between 2009 and 2014. Many of these cases occurred while the battery was being charged or stored [24]

Much of the LIB research performed has focused on "abusive" conditions or manufacturing defects, however, even in non-abusive conditions, lithium-ion batteries can still cause fires, even during storage. Between 1991 and 2018, 238 airports reported fire incidents related to LIBs transported as cargo or baggage and there have also been at least two fires from LIB manufacturer

and warehouses in the UK and China. Through a study done on LIBs being packaged or stored in bulk, it was found that when individual cells are packaged together, in this case a box of 100, the self-ignition temperature is 30 degrees C lower than for a single cell [25]

In the United States alone, a flight is grounded on average every 10 days due to a lithium-ion battery fire. The same problem is affecting e-cigarettes where they have been "blowing up in people's faces sporadically" [26].

Some of the LIB problems can be attributed to dendrites, tiny structures that form on an electrode, which have the potential to pierce through the battery separator and create an internal short circuit. These dendrites cause internal short circuits which then build up enough heat to lead to the cells catching fire. Once this occurs, it could then cause adjacent cells to overheat leading to the entire pack exploding. This process can develop over many charge/discharge cycles before it reaches the point of failure. During charge cycles, the dendrites will start to grow, but during discharge periods, lithium ions are pulled out of the anode and the dendrites are reduced. Each cycle creates more cracks in the separator until eventually, the dendrite growth is sufficient to create a short [26,27].

It is well documented that LIBs, including 18650s, pose a fire risk. A newly published book titled Electrical Fires and Explosions devotes 13 pages to LIB fires that also summarizes much of the information present above [31]. (note: the number 31 needs to be added on page A3) There are many ways a LIB can enter thermal runaway. This condition is not unusual, and the result is a fire or explosion. Fire hazards associated with LIBs have been documented through literature, safety standards, and the CPSC. Battery manufacturers have worked to incorporate safety features to minimize these catastrophic events, and governments and other groups have created safety standards; however, it has been shown these efforts have not been completely successful in preventing fires and explosions.

V. TESTING

Results of testing at SAFE Labs involving 18650 LIB cells is consistent with the literature. The 18650 cells tested are also consistent with those identified in the subject hoverboard. The testing involved short circuit and puncture testing, similar to that referenced in the literature described above.

A. Short Circuit

The basis of Mr. Sudler's opinion appears to be an assumption that the internal resistance of the subject LIB is around 50 milliOhms. From this he calculates a fault (short circuit) current of 12.6 A. This is inconsistent with the short circuit current reported in the literature and it is also inconsistent with the results of testing performed at SAFE Labs on Samsung and LG labeled hover board batteries.

Figure 1 through Figure 6 show photographs of 2 battery packs removed from 2 different hoverboards. Both of these battery packs have the same ratings, 36 V and 4400mAh. These ratings are also consistent with the ratings reportedly associated with the subject hover board and the ratings used in Mr. Sudler's calculations.

Three LG labeled cells removed from one hoverboard and three Samsung labeled cells removed from a second hoverboard were individually charged to 3.7 V, the voltage used in Mr. Sudler's calculations. Each cell was then individually subjected to short circuit testing. A photograph of the short circuit test is shown in Figure 7. Pressure connections were made between the positive and negative terminal of each cell and braided, plated, copper conductors. The braided conductors connected to the positive and negative terminal of the battery were then connected together, creating a short circuit with the braided conductor. Current flow through the braided conductor was monitored with an LEM current transducer and logged with an HBM transient recorder using a 100Hz sample rate. Cell voltage was also acquired at the same sample rate.

The short circuit current measured at SAFE Labs was far greater than the short circuit current calculated by Mr. Sudler. For both the LG and Samsung labeled cells, the short circuit current was on the order of 80 A. The LG labeled cell produced slightly above 80 A while the Samsung labeled cell produced slightly below 80 A. The Samsung labeled cell likely incorporated an internal CID, as the short circuit current was suddenly interrupted after only a few seconds. The LG labeled cell, on the other hand, continued flowing short circuit current until the energy within the cell was mostly depleted. Screen captures of this data can be seen in Figure 8 and Figure 9.

Figure 1. A photograph showing the label on a 36 V 4400mAh battery pack removed from a hoverboard and containing cells marked "LG".

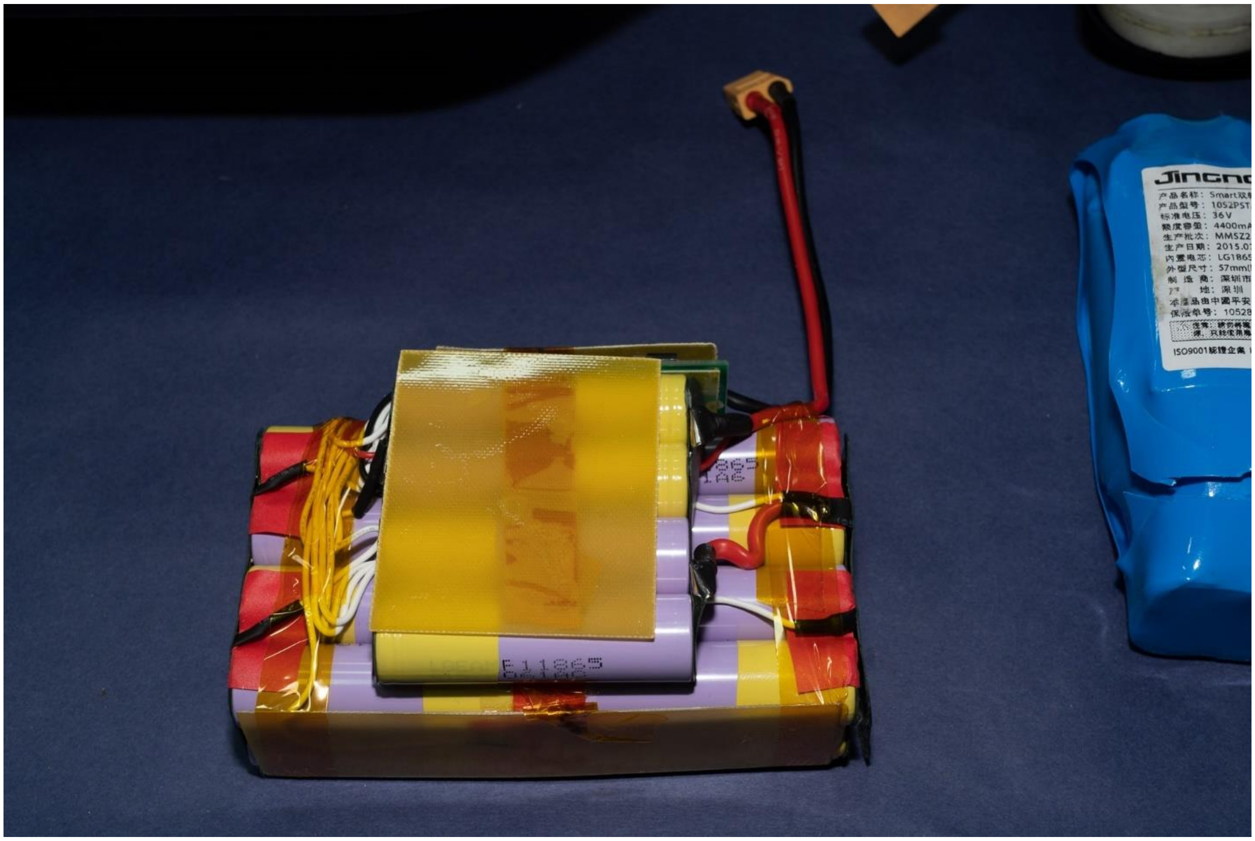


Figure 2. A photograph of the cells inside the wrapper shown in Figure 1.

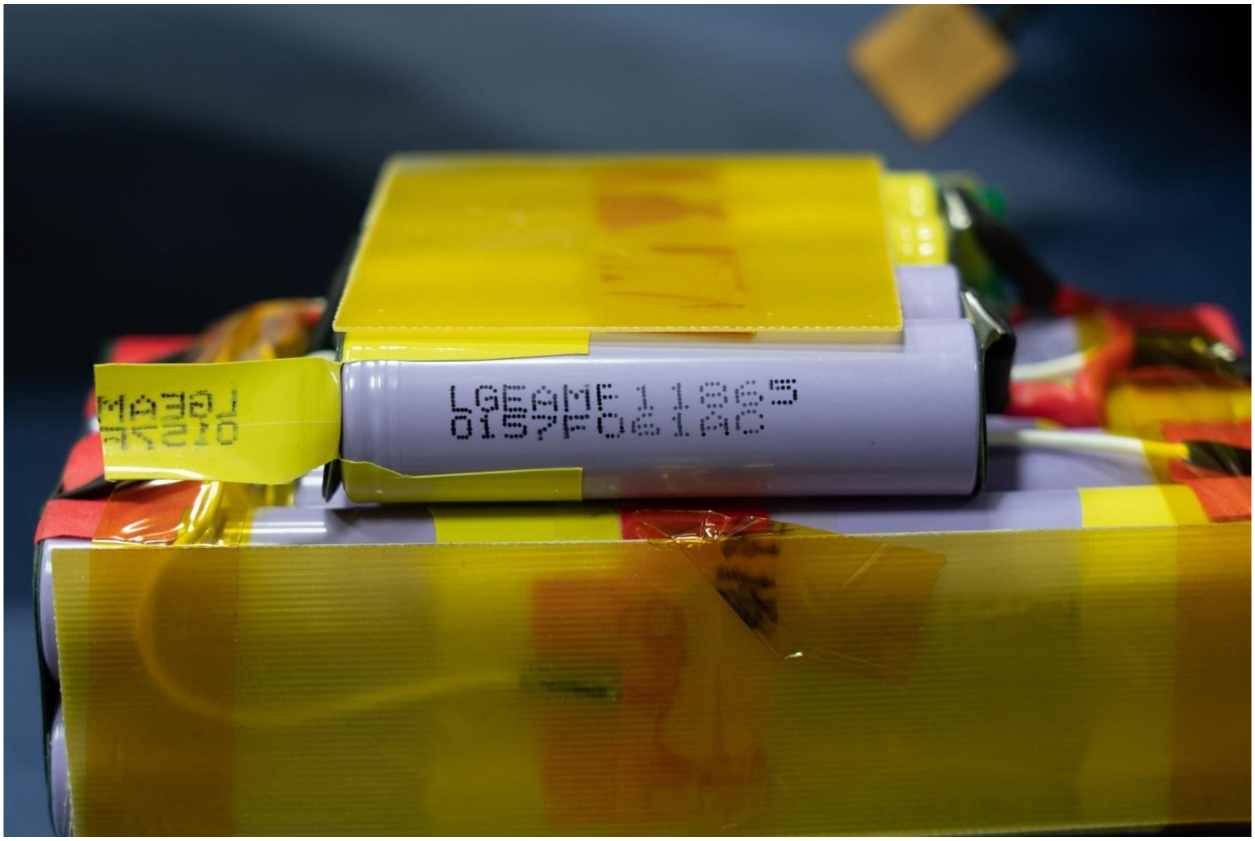


Figure 3. A close-up view of the markings on a single cell.

Figure 4. A photograph showing the label on a 36 V 4400mAh battery pack removed from a second hoverboard and containing cells marked "Samsung".

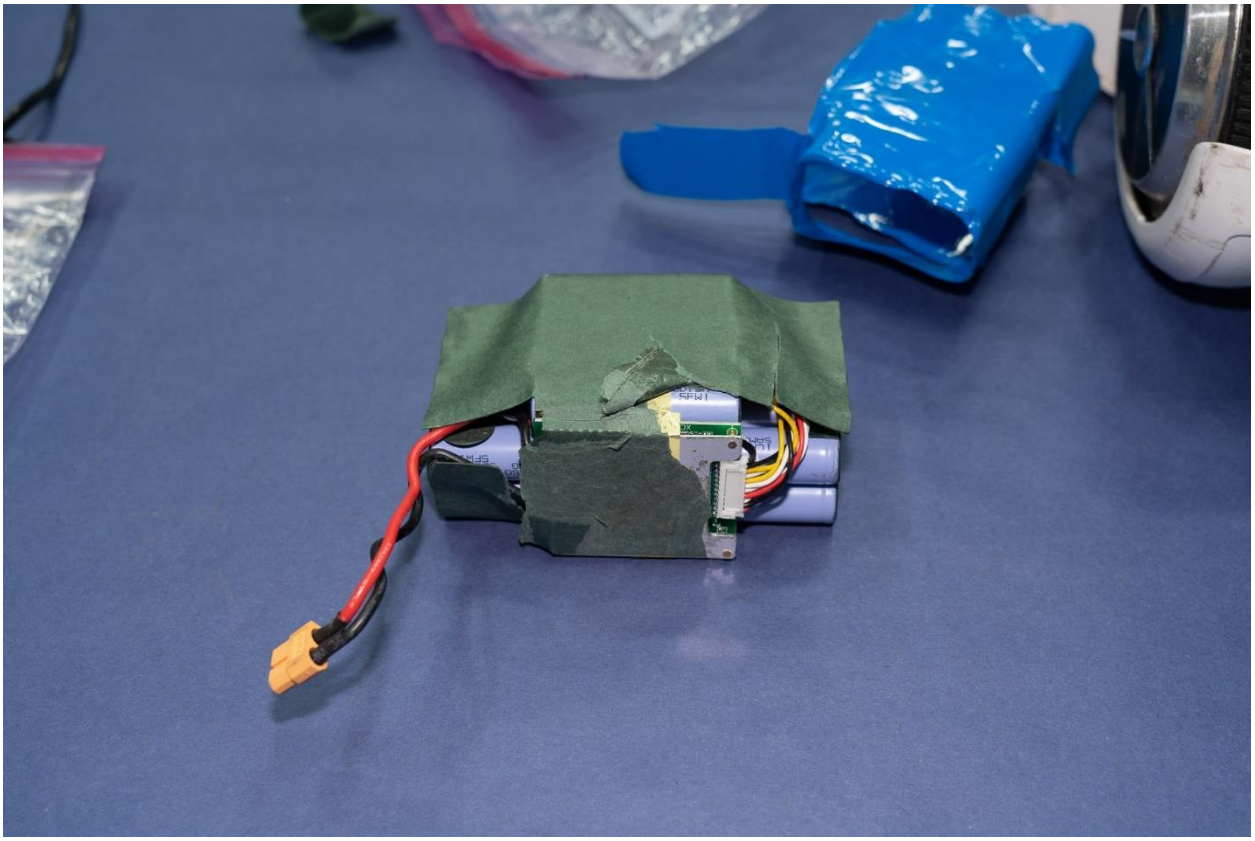


Figure 5. A photograph of the cells inside the wrapper shown in Figure 4.

Figure 6. A close-up view of the markings on a single cell.

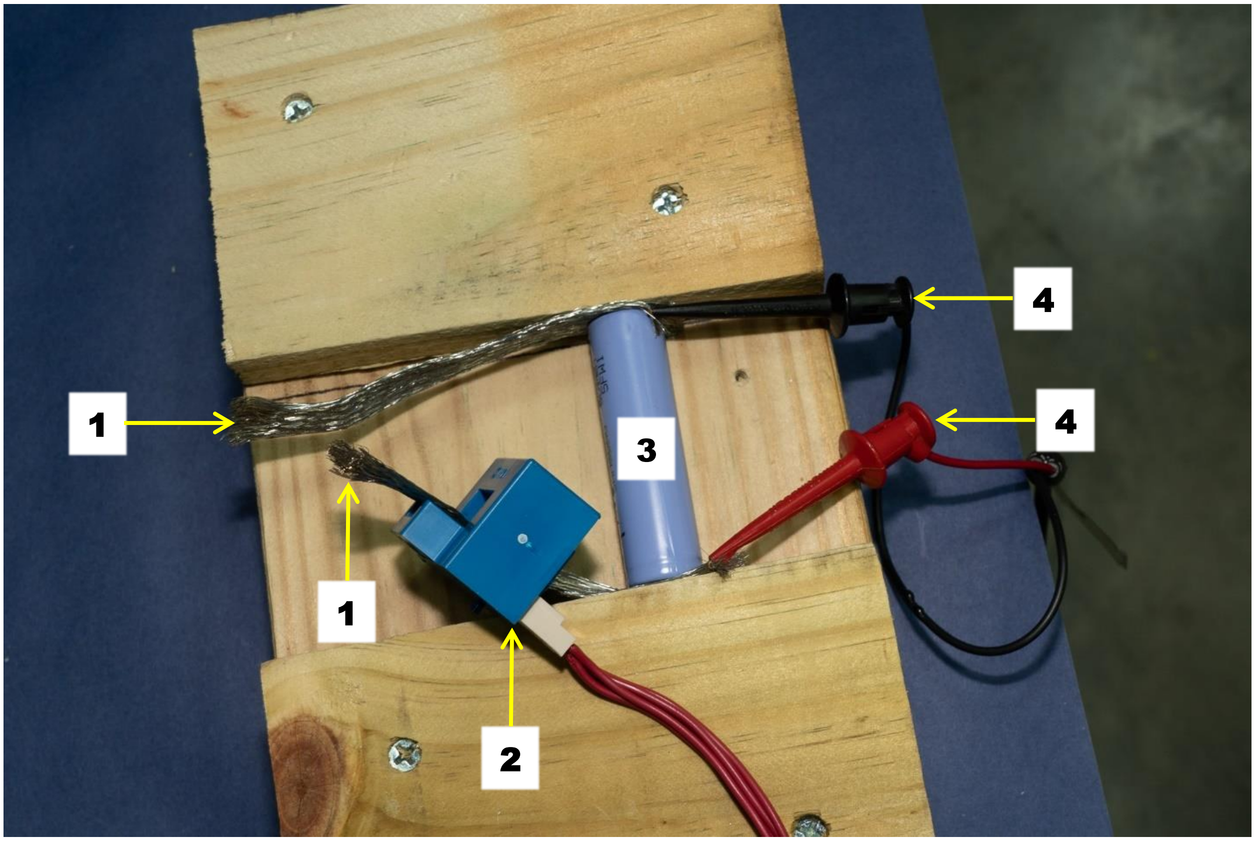


Figure 7. A photograph showing the cell short-circuit test set up.

Notes:

1. Braided conductors, clamped together to create a short-circuit
2. Current transducer around braided conductor connected to the cell positive terminal
3. 18650 cell
4. Voltage probes

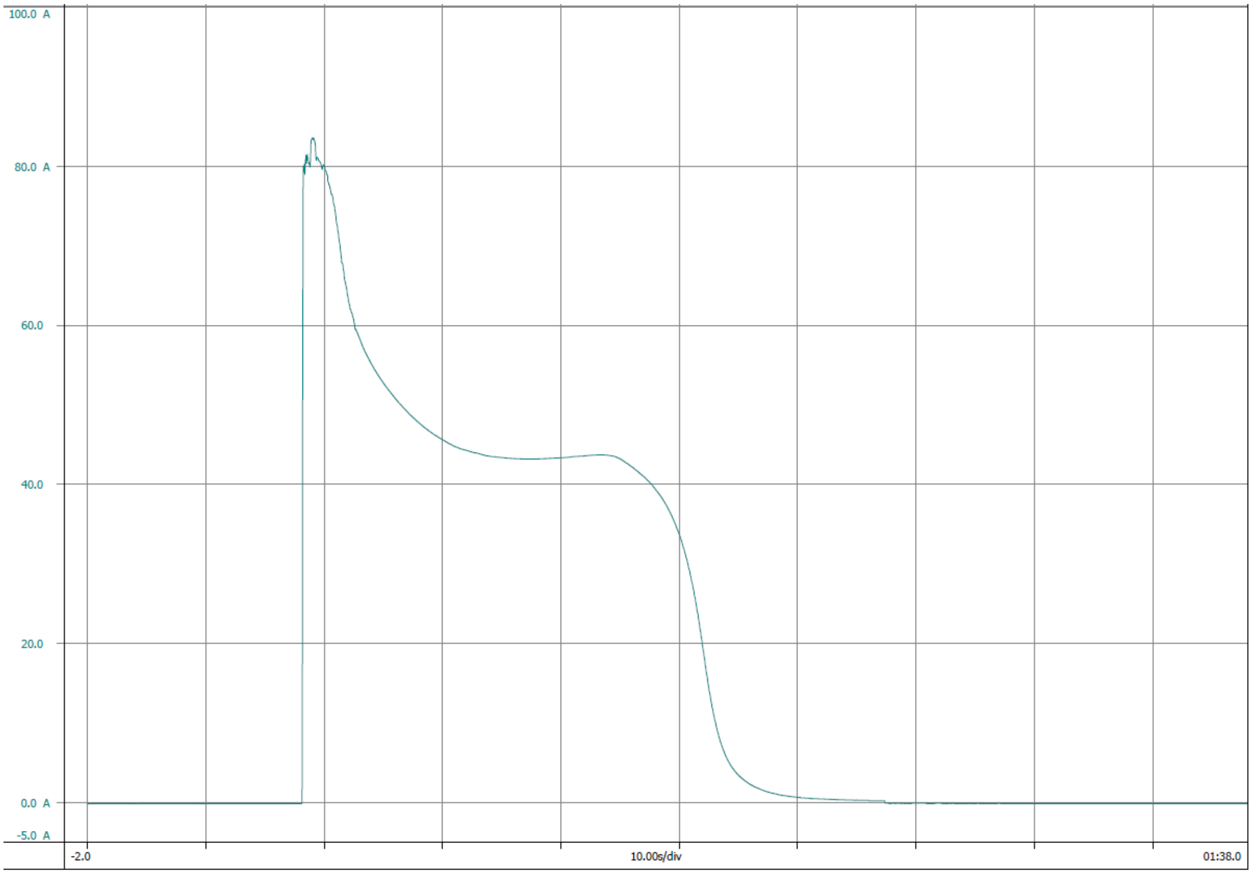


Figure 8. Screen capture showing the short-circuit current produced when an LG labeled cell was short circuited.

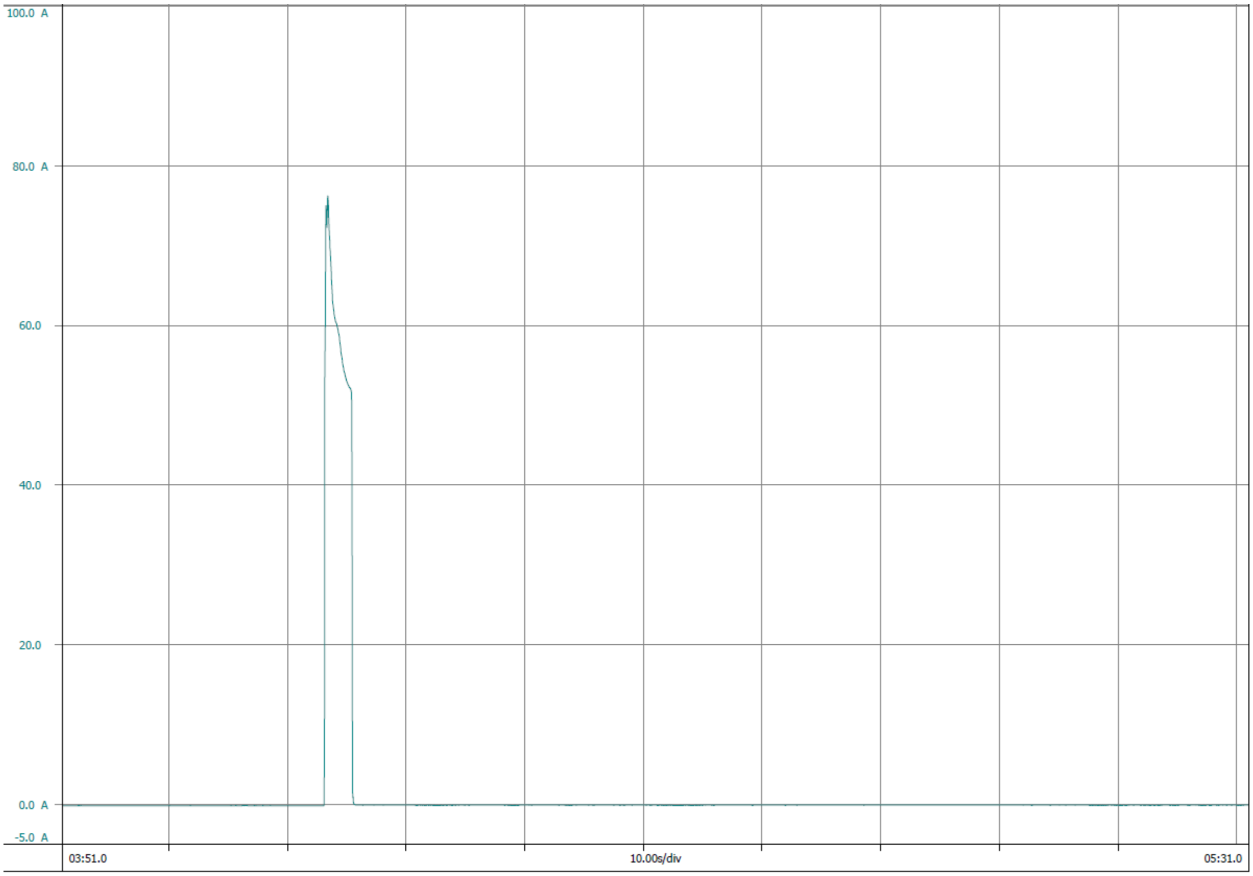


Figure 9. A screen capture showing the short circuit current produced when a Samsung labeled cell was short-circuited.

B. Puncture

Puncture testing was also performed on both the LG and Samsung labeled cells. Puncturing the cell created an internal short-circuit between the anode and the cathode, which led to thermal runaway. Puncturing the cell was achieved using a 3-inch wood screw driven into the side of each cell. A hole slightly larger than an 18650 cell was bored through a standard 2 x 6 piece of wood. An 18650 cell was inserted into the hole and approximately centered in the 2 x 6. The 3-inch wood screw was then driven down through the 2 x 6 and into the 18650 cell. This process was video recorded and screen captures from the video are shown in Figure 10 (a Samsung labeled cell), and in Figure 11 (an LG labeled cell). Both tests produced violent results, as the literature discusses. Flames, hot gases, molten particles, and other internal cell components were violently ejected from the cell. For the Samsung labeled cell, this occurred in conjunction with a loud “bang”, similar to a gunshot. For the LG labeled cell, this occurred in conjunction with a loud “whoosh” sound. Flames emanating from the Samsung labeled cell persisted for several seconds. Flames emanating from the LG labeled cell did not last as long, but the metal 18650 housing glowed red for several seconds and the cell remained hot long enough to cause the 2 x 6 to start smoldering. This can be seen in Figure 12. The smoke intensity was still increasing when the LG labeled cell was removed from the 2 x 6. Left in place, the 2 x 6 would likely have ignited.

Prior to puncturing the cells with a screw, other puncture testing was performed by striking the 18650 cells with heavy, blunt objects. This produced various results, as it was difficult to strike the 18650 cells with the same force and in the same position for each test. However, in one case the cell clearly went into thermal runaway, ejecting hot gases, sparks, products of combustion, and cell contents as it thrust itself through the air, landing about 20 feet away.

This testing is consistent with the literature and prior testing performed on 18650 cells at SAFE Labs.

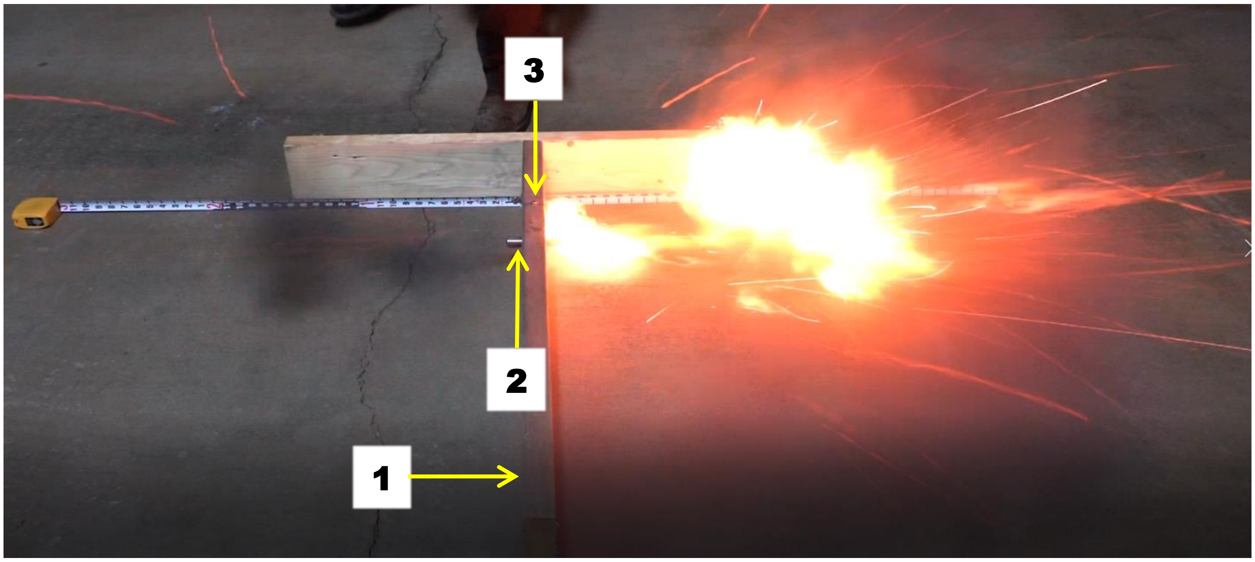


Figure 10. A screen capture from a video showing a Samsung cell producing approximately a 3-foot flame after an internal short-circuit was created.

Notes:

1. 2 x 6 wood stud on edge with the hole bored in the center
2. 18650 cell placed through bored hole
3. 3-inch wood screw driven through the 2 x 6 and into the 18650 cell

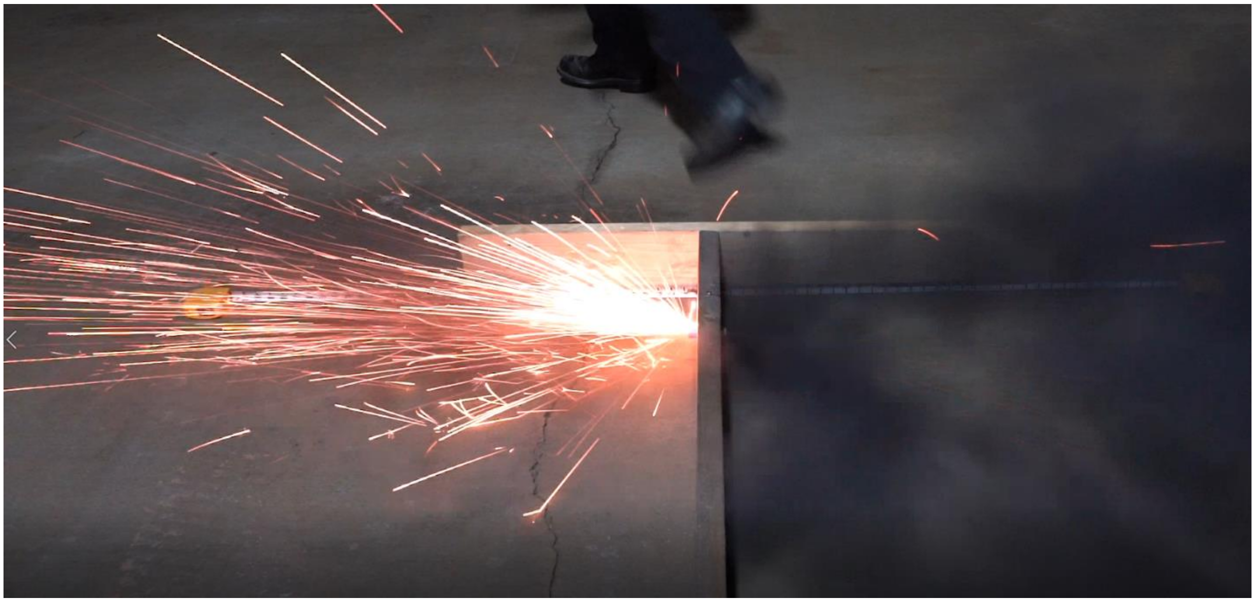


Figure 11. A screen capture showing an LG cell producing a flame and ejecting flaming particles well over 3 feet after an internal short circuit was created.

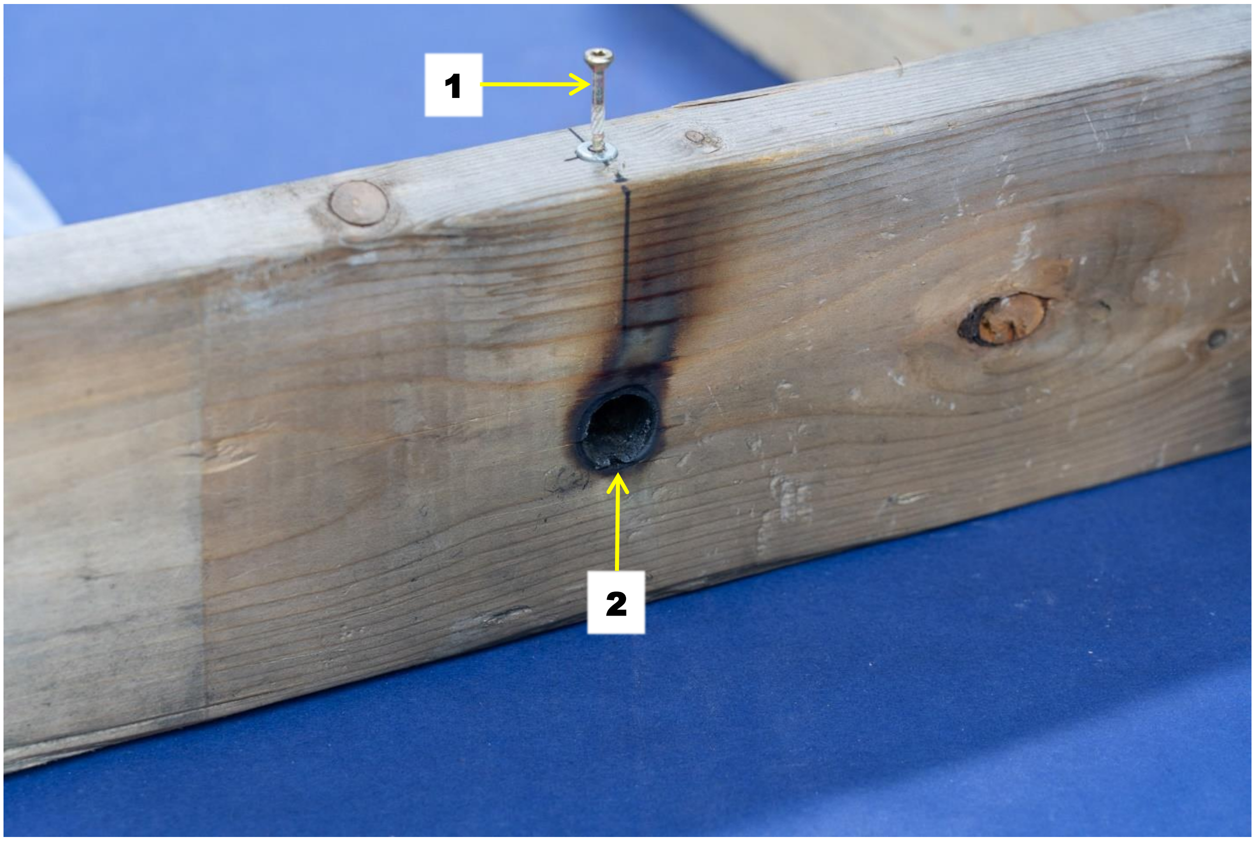


Figure 12. A photograph showing the charred bored hole inside of a 2 x 6.

Notes:

1. 3-inch wood screw
2. Charred bored hole in 2 x 6

VI. CONCLUSIONS

1. There is more than enough energy in the subject cell 4H to ignite nearby combustibles and trigger thermal runaway in adjacent cells. A single 18650 cell experiencing a thermal runaway condition will not only produce significant amounts of heat, but also eject flaming gasses and particles, much like a torch, and trigger nearby cells to also enter thermal runaway.
2. A single 18650 cell, including the subject cell, is a viable ignition source.

APPENDIX A. REFERENCES

[1] Y. Chen, Y. Kang and e. al, "A Review of Lithium-Ion Battery safety concerns: the issues, strategies and testing standards," *Journal of Energy Chemistry,* vol. 59, pp. 83-99, 2020.

[2] A. Golubkov, R. Planteu and e. al, "Thermal runaway of large automotive Li-ion batteries," *Royal Society of Chemistry,* vol. 8, pp. 40172-70186, 2018.

[3] D. Ouyang, M. Chen and e. al, "A review on the thermal hazards of the lithium-ion battery and the corresponding countermeasures," *MDPI,* vol. 9, no. 2483, pp. 1-45, 2019.

[4] LG Chem, "Technical Information of LG 18650HE2," LG Chem, 2013.

[5] Samsung SDI, "Introduction of INR18650-25R," Samsung SDI - Energy Business Division, 2013.

[6] PowerStream, "PowerStream," 27 March 2019. [Online]. Available: https://www.powerstream.com/18650-high-discharge-rate.htm.

[7] T. Nguyen, S. Abada and e. al, "Understanding the thermal runaway of Ni-rich LIB," *MDPI - World Electric Vehicle Journal,* vol. 10, no. 79, pp. 1-24, 2019.

[8] L. Rong, X. Cheng and Y. Fu, "Effects of states of charge on the burning behaviors of lithium ion batteries," *IEEE International conference on fire science and fire protection engineering,* 2019.

[9] D. Finegan, E. Darcy and e. al, "Identifying the cause of rupture of li-ion batteries during thermal runaway," *advanced science,* vol. 5, pp. 1-13, 2018.

[10] E. Darcy, "Insights from safety tests with an on-demand internal short circuit device in 18650 cells".

[11] M. Spielbauer, M. Ringat and e. al, "Experimental study of the impedance behavior of 18650 lithium-ion battery cells under deforming mechanical abuse," *The Journal of Energy Storage,* vol. 26, pp. 1-13, 2019.

[12] V. Ruiz, A. Pfrang and etal, "A review of international abuse testing standards and regulations for lithium ion batteries in electric and hybrid electric vehicles.," *Renewable and sustainable energy reviews,* 2018.

[13] H. Yan, K. Marr and O. Ezekoye, "Towards fire forensic characteristics of failed cylindrical format lithium-ion cells and batteries," *Spring Science - Fire Technology,* pp. 1-30, 2021.

[14] X. Yao, L. Kong and M. Pecht, "Reliability of cylindrical li-ion battery safety vents," *IEEE Access,* vol. 8, pp. 1-8, 2020.

[15] A. Augeard, T. Singo, P. Desprez and M. Abbaoui, "Contribution to the study of electric arcs in lithium-ion batteries," *IEEE Transactions on components, Packaging and Manufacturing Technology,* vol. 6, no. 7, pp. 1066-1076, 2016.

[16] Consumer Product Safety Commision, "Self-balancing scooters/hoverboards recalled by 10 firms due to fire hazard," CPSC.gov, 2016.

[17] CPSC , "LG Home recall," [Online]. Available: https://www.cpsc.gov/Recalls/2020/lg-energy-solution-michigan-recalls-home-energy-storage-batteries-due-to-fire-hazard.

[18] Consumer Product Safety Commission, "CPSC issues consumer safety warning: serious injury or death can occur if lithium-ion battery cells are separated from battery packs and used to power devices," CPSC.gov, 2021.

[19] LG Chem, "Li-Ion battery safety guide," lg chem.

[20] LG CHEM, "stay safe," [Online]. Available: www.staysafebattery.com/en.

[21] Consumer Product Safety Commission, "HP expands recall of batteries for HP and Compaq Notebook computers due to fire and burn hazards," CPSC.gov, 2017.

[22] L. Binghe, C. Yuan, J. Yikai and W. Lubing, "Safety issues and mechanisms of lithium-ion battery cell upon mechanical abusive loading: a review," *Energy Storage materials,* vol. ENSM 825, 2020.

[23] K. Nicoll, A. Rose, M. Khan, O. Quaba and A. Lowrie, "Thigh burns from exploding e-cigarette lithium ion batteries," *Journal of the International Society for Burn Injuries,* 2016.

[24] Z. Alisha, K. Chung, J. Rizzo and L. Cancio, "Thermal Injury patterns associated with electronic cigarettes," *International Journal of Burns and Trauma,* vol. 7, pp. 1-5, 2017.

[25] Z. Hu, X. He, G. Rein and F. Restuccia, "Numerical study of self-heating ignition of a box of lithium-ion batteries during storage," *Fire Technology,* vol. 56, pp. 2603-2621, 2020.

[26] L. B and Y. Cui, "Less Fire, More Power," *IEEE Spectrum,* vol. September, pp. 44-48, 2018.

[27] D. Ouyang, M. Chen and e. al, "Investigation of a commercial lithium-ion battery under overcharge/over-dicharge failure conditions," *Royal Society of Chemistry ,* vol. 8, pp. 33414-33424, 2018.

[28] F. Larsson and B. Mellander, "Abuse by external heating, overcharge and short circuiting of commerical lithium-ion battery cells," *Journal of the Electrochemical Society,* vol. 161, no. 10, pp. 1611-1617, 2014.

[29] J. Jeevarajan, "Safe lithium-ion battery designs for use, transportation and second use," Underwriters Laboratories, Fr. Lauderdale, 2016.

[30] L. M. Jr., "Electronic cigareet fires and explosions in the united states," U.S. Fire Administration - National Fire Data Center, 2016.

[31] Babrauskas, Vytenis, *Electrical Fires and Explosions*, Fire Science Publishers, 2021.

APPENDIX B. ITEMS THAT MAY BE USED IN DEPOSITION OR TRIAL

Entire CORE Engineering file

Entire SAFE Labs file

Photographs of the exemplar hoverboards

Videos of the cell testing

Data obtained from cell testing

CT scans of exemplar cells

CT scans of subject cells

Exemplar hoverboards

SEA report

This report and items referenced in this report

APPENDIX C. CV

John P. Cavaroc, Ph.D., P.E.
Electrical Engineer / President
SAFE Laboratories and Engineering Corp
5901 Elwin Buchanan Drive
Sanford, NC 27330
919-632-3049
jcavaroc@safe-labs.com

EDUCATION

2007 **Ph.D. Electrical Engineering**
North Carolina State University, Raleigh, North Carolina

1998 **M.S. Electrical Engineering**
North Carolina State University, Raleigh, North Carolina

1996 **B.S. Electrical Engineering**
Louisiana Tech University, Ruston, Louisiana

EXPERIENCE

June 2011 to Present Electrical Engineer / President, SAFE Laboratories and Engineering Corp, Sanford, North Carolina.

- Determine the origin and cause of fires and explosions, the cause of personal injury, and the cause of property damage.
- Analyze electrical equipment and devices, wiring, control systems, electrical connections, electrical service and power quality events, electromechanical systems, and electrical installations code compliance.
- Analyze electrocution, electric shock, lightning strike, and arc flash events.
- Perform electrical and electronic equipment and device testing

October 2008 to May 2011 Consulting Electrical Engineer, The Warren Group, Inc., Columbia, South Carolina.

- Determine the origin and cause of fires and explosions, the cause of personal injury, and the cause of property damage.
- Analyze electrical equipment and devices, wiring, control systems, electrical connections, electrical service and power quality events, electromechanical systems, and electrical installations code compliance.
- Analyze electrocution, electric shock, lightning strike, and arc flash events.
- Perform electrical and electronic equipment and device testing

EXPERIENCE, Continued

2007 - 2008 Consultant, Self Employed, Pittsboro, North Carolina

- Determined the failure mechanism of a mechanical failure involving a 9,875 HP induction motor and driven equipment. Used field data from induction motors, driven equipment, and plant electrical diagram to create a mathematical model of the system. Performed a parameter estimation and simulation of the system in order to show the sequence of events and torques generated before, during, and after the failure.
- Established communication between a novel implantable medical sensor device and PC using USB and high-speed networking protocols. Troubleshot and repaired problems with implant circuit. Collaborated with engineers and medical doctors during surgery about implanted circuit data acquisition methods. Designed user interface for real time data acquisition.
- Collaborated on the design of a portable data acquisition device for medical applications. Performed design, schematic capture, simulation, PCB layout, testing, troubleshooting, and repair of prototype circuits.
- Created user interface and established communication between multiple instruments and PC in a test stand for novel optical device characterization.

2004 - 2007 Group Leader/Research Engineer, Microcell Corporation, Raleigh, North Carolina

- Directed a multi-disciplined team of engineers, technicians, and production personnel in the development and production of novel PEM hydrogen fuel cell modules and systems.
- Installed extrusion line exhaust system; shop lighting and HVAC system; conduit and feeders for electrical service to new addition; hydrogen detection system and alarm; hydrogen, air, and nitrogen distribution system; data and communication circuits; electrical infrastructure for extrusion line; and replaced damaged main breaker in distribution panel.
- Troubleshot and repaired electronic loads, ultrasonic cleaners, ultrasonic welder, homogenizers, air compressor, custom lab equipment, and extrusion line equipment.
- Collaborated with electric utility on integration of backup power and distributed generation systems in substations, telecommunications facilities, and residences.
- Designed and constructed prototype hydrogen fuel cell power systems for stand alone and telecommunication backup power applications.
- Designed and constructed novel electromechanical automatic production equipment, replacing labor intensive production methods and causing a dramatic increase in production volume.
- Designed and constructed 1kW hollow fiber fuel cell module, delivered prototype to major Japanese automotive manufacturer and trained high level engineers on module operation.
- Solved fundamental problems in faulty manufacturing methods that caused early fuel cell failure and prevented large scale production and long-term testing.
- Designed and constructed custom test stands for fuel cell testing, including data acquisition, online resistance measurement, gas flow management, thermal management, power management, remote access, and emergency shut down.
- Defined production methods, hired and trained production technicians and supervisors.
- Hired and trained research and development engineers and technicians.

EXPERIENCE, Continued

2000 - 2004 Consultant/Principle Investigator, Advanced Energy Corporation, Raleigh, North Carolina

- Organized and directed electric utility driven study on induction motor ride- through performance during power supply disturbances.
- Presented data and ideas to industry, resulting in a commercial smart ride-through controller for induction motors.
- Designed and constructed custom portable 600VAC, 400A solid state point-on-wave interruption/sag generator.
- Conducted sag and interruption tests on industrial equipment located in the field.
- Designed and constructed data acquisition system capable of simultaneously sampling three phase voltage, three phase current, shaft torque, and shaft speed at 1MHz.
- Automated and synchronized interruption / sag generator with data acquisition system, allowing multiple tests without user input.
- Developed mathematical model and parameter estimation method for motor/load system.
- Conducted comprehensive voltage interruption tests on 10 HP, 50 HP, and 75 HP motors.
- Assisted with IEEE 112B motor efficiency tests on fractional HP motors up to 200 HP.
- Troubleshot and repaired 600 VAC, 200 A three phase variacs, motor control circuits, and motor lab test equipment.

1996 - 2000 Research Assistant /Teaching Assistant, North Carolina State University, Raleigh, North Carolina

- Conducted field trials of contactor ride through device.
- Acquired data for line impedance modeling.
- Conducted power electronic device characterization tests.
- Measured and characterized contact impedance of pressure contacts on prototype modules for the Power Electronic Building Block project.
- Troubleshot and repaired power amplifier.
- Coordinated Circuits I lab. Trained teaching assistants, developed course material, managed 16 lab sections, and instructed labs.
- Periodically substituted as an instructor for graduate Power Electronics course, undergraduate Power Electronics course, Electromagnetic Fields course, Principles of Electrical Engineering course, Circuits I course, and Circuits II lab.

EXPERIENCE, Continued

1999-Present (Part Time)

Electrician / President, Wire Nuts, Inc., Sanford, North Carolina

- Wire new houses, re-wire existing houses, commercial fit-ups, provide outdoor lighting circuits, provide power to shops/garages.
- Troubleshoot and repair lighting, receptacle, and GFCI circuits, HVAC systems, septic systems, fire alarm systems, and lightning damaged equipment.
- Inspect electrical systems.

2000 - 2001 (Part Time)

Emergency Medical Technician (EMT), Garner EMS, Garner, North Carolina

- Provided emergency medical service for events at Walnut Creek Amphitheater.

1996 - 2002 (Volunteer)

Assistant Chief/Board Member/Captain /Engineer/Fire Fighter, Garner Volunteer Fire Department, Garner, North Carolina

- Assumed command on fire, rescue, HAZMAT, and EMS calls.
- Conducted fire suppression, search and rescue, ventilation, rescue tool operation, pumper and tanker operations on fire and rescue calls.
- Conducted emergency medical care on EMS calls.
- Organized and directed emergency medical First Responder program at Station 1.
- Provided interviews and information to the news media.
- Collaborated with Wake County Training Officers and Wake County Fire Investigators.
- Assessed applicants for promotion during Wake County Officer Assessment Centers.
- Managed annual budget.

1992 - 1996 (Volunteer / Part Time)

Assistant Chief/Maintenance Supervisor/Engineer/Firefighter/Charter Member, Lincoln Parish Fire Protection District No. 1, Vienna, Louisiana

- Assumed command on fire calls.
- Conducted fire suppression, search and rescue, ventilation, pumper, tanker and water shuttle operations on fire calls.
- Organized and conducted training exercises.
- Installed and maintained mechanical and electrical equipment in 20 fire stations.
- Maintained fire apparatus and equipment.
- Retrofitted new vehicles for emergency service use.
- Rebuilt 20 defective 2500-gallon fiberglass tanker water tanks.

EXPERIENCE, Continued

1991 - 1995 (Summers)

Engineering Aid / Electrician's Apprentice, SECO Industries, Metairie, Louisiana

Locations and projects included:

- McDermott Fabrication Yard, Amelia, Louisiana, Shell "Mars" Tension Leg Platform, Exxon "Mobile Bay Project", Freeport MacMoran "Main Pass Sulphur Mine"
  Installed cable tray, high voltage cable, control cable, feeder cable, conduit, wires, process control instruments, stainless steel tubing, and tubing tray for process control and fire suppression systems. Updated tracking files, improved tracking software, updated drawings, processed data for progress reports, and performed correct mounting and installation Quality Assurance inspection of process control instruments.
- Amerada Hess Bulk Oil Storage Facility, Marrero, Louisiana.
  Troubleshot and corrected 480V lighting and motor starter problems, rebuilt 2400V oil submersed motor starters following lightning damage.
- Bender Ship Yard, Braithwaite, Louisiana "The Rouge" and "The Treasure Chest" riverboats casinos
  Terminated controls for ship board fire protection system and Z, drive system, troubleshot and corrected grounding problems identified by US Coast Guard, installed feeder and control cables.
- Louisiana Offshore Oil Port, Galliano, Louisiana
  Constructed and installed new control cable termination panels for 6000 HP. 13.8KV motors, replaced lighting ballasts.
- Aker Gulf Marine Fabrication Yard, Ingleside, Texas, Dresser Rand "Portable Turbo Gas Compressor Station Project"
  Installed stainless steel tubing and instruments for process monitoring, control, and fire protection systems, collaborated with welders on the installation of electrical equipment and instruments.
- Chevron Oronite Chemical Plant, Belle Chasse, Louisiana
  Assisted with installation of conduit, wire, and 240V receptacle outlets on railroad loading dock.

PROFESSIONAL ORGANIZATION MEMBERSHIP

National Fire Protection Association (NFPA)

Institute of Electrical and Electronics Engineers (IEEE)

National Association of Fire Investigators (NAFI)

International Association of Arson Investigators (IAAI)

Pyrotechnics Guild International (PGI)

PROFESSIONAL COMITTEES AND TASK GROUPS

Alternate committee member for NFPA 1321 – Standard for Fire Investigation Units

Arc Mapping Task Group member for NFPA 921 – Guide for Fire and Explosion Investigations

REGISTRATIONS, CERTIFICATIONS, AND LICENSES

Professional Engineer, North Carolina (#029412), South Carolina (#28866), Alabama (#31765), Georgia (#35574), Mississippi (#20161), Tennessee (#114917), Florida (#73524), Virginia (#0402054043)

Electrical Contractor, North Carolina (#23164-I)

Certified Fire and Explosion Investigator (#13845, 6995)

The National Council of Examiners for Engineering and Surveying (NCEES) (#31492)

North Carolina Outdoor Pyrotechnics Display Operator (#3826)

PATENTS

"Power supply systems and methods that can enable an electromagnetic device to ride-through variations in a supply voltage," US Patent 6,847,515, January 25, 2005.

Multiple patents pending on hydrogen fuel cell assemblies and assembly methods.

ADDITIONAL SKILS

- Analog, digital, electrical, electro-mechanical, and mechanical design, modeling, and simulation
- Schematic capture, Printed Circuit Board (PCB) layout
- Excellent troubleshooting skills
- Knowledge and understanding of the National Electrical Code (NEC)
- Industrial, commercial, and residential electrical and instrumentation installation
- Computer Numerical Control (CNC) and manual machining of metal, plastics, composite materials, and wood
- Ultrasonic metal welding, brazing, soldering
- Experience using urethanes, epoxies, and silicones as adhesives, sealants, molds, encapsulants, and structural members.
- Software: Labview, TurboCAD/CAM, Visio, Mentor Graphics PADS and DxDesigner, Circad, SPICE, IGOR, Visual Basic, Matlab/SIMULINK, Mathcad, COMSOL

CONTINUING EDUCATION

Generic Fall Protection
December 26, 2020, NANTeL, 1 hour, Sanford, NC

Hazardous Wastes Operations and Emergency Response (HAZWOPER) Refresher
November 6, 2020, Emergency Response Training, 8 hours, Sanford, NC

NFPA 70E and Arc Flash 8hr.
August 20, 2020, Scott Peele, P.E., 8 Hours, Sanford, NC

Hazardous Wastes Operations and Emergency Response (HAZWOPER) Refresher
November 8, 2019, Emergency Response Training, 8 hours, Sanford, NC

Grounding and Bonding, Safety
June 29, 2019, Mike Holt Enterprises, 8 hours, Coral Springs, FL

2019 Ethics for Florida Engineers
February 27, 2019, PDH Library, Online Curriculum, 1 hour, Sanford, NC

Florida Laws and Rules (2019)
February 27, 2019, PDH Library, Online Curriculum, 1 hour, Sanford, NC

2017 NC Electrical Code Changes
February 16, 2019, North Carolina Association of Electrical Contractors, 8 hours, Carthage, NC

Pyrotechnic Display Operator
February 9, 2019, Hale Artificier, Inc., 8 hours, Lexington, NC

Rules and Laws
January 31, 2019, North Carolina State Board of Examiners of Electrical Contractors, 4 hours, Jacksonville, NC

Hazardous Wastes Operations and Emergency Response (HAZWOPER) Refresher
November 2, 2018, Emergency Response Training, 8 hours, Sanford, NC

NEC Continuing Education Review
February 24, 2018, Yadkin Electrical Services Co., 8 hours, Asheboro, NC

Hazardous Wastes Operations and Emergency Response (HAZWOPER) Refresher
November 11, 2017, Emergency Response Training, 8 hours, Sanford, NC

2017 FL Laws and Rules and 2017 Ethics for Florida Engineers
February 28, 2017, PDH Library, Online Curriculum, 2 hours, Sanford, NC

Advanced Trial Skills for Expert Witnesses
May 12-13, 2016, SEAK, 14 hours, Chicago, IL

National Expert Witness Conference
May 14-15, 2016, SEAK, 14 hours, Chicago, IL

X-ray / CT Training using Inspect-X, CTPro3d, and VGStudio Max
May 5, 2016, Nikon Metrology, Inc., 32 hours, Sanford, NC

CONTINUING EDUCATION, Continued

Overview of Articles 90-220 and Electrical Rough-in Requirements
February 19, 2016, Keith Educational Seminars, 8 hours, Wilson, NC

2014 Changes to the NEC Part 1
February 28, 2015, Mike Holt Enterprises, Online Curriculum, 8 Hours, Chapel Hill, NC

Laws & Rules Online
February 28, 2015, SunCam, Inc., Online Curriculum, 4 Hours, Chapel Hill, NC

Mississippi PE – Ethics Review
December 31, 2014, Professional Online Educators, Inc., Online Curriculum, 1 Hour, Chapel Hill, NC

NFPA 70E and Arc Flash 8hr.
December 13, 2014, Scott Peele, P.E., 8 Hours, Raleigh, NC

8-Hour HAZWOPER Refresher for Environmental Professionals
December 11, 2013, NC State University Industrial Extension Service, 8 Hours, Raleigh, NC

Florida Engineers' Laws and Rules [V.11]
February 25, 2013, Red Vector, Online Curriculum, 4 Hours, Raleigh, NC

Mechanical Characteristics of Conductors
February 25, 2013, Red Vector, Online Curriculum, 4 Hours, Raleigh, NC

HAZWOPER 8HR Refresher
December 14, 2012, Compliance Solutions, 8 hours, Raleigh, NC

NFPA 70E Low Voltage Qualified Training
June 29, 2012, E-Hazard Management, LLC, 8 hours, Greensboro, NC

HAZWOPER 40HR Certification
February 21, 2011, North Carolina State University, 40 hours, Raleigh, NC

Detailed Electrical Code Workshop
February 6-7, 2010, JCR Productions, Inc., 24 hours, Asheville, NC

Bonding & Grounding Electrical Code Workshop
February 5, 2010, JCR Productions, Inc., 8 hours, Asheville, NC

Expert Report Writing
January 20, 2010, International Association of Arson Investigators, Inc., 8 hours, Charlotte, NC

HAZWOPER Site Supervisor and Manager Certification
May 26, 2009, Chicago Safety Institute, 8 hours, Chicago, IL

HAZWOPER 40HR Certification
May 26, 2009, Chicago Safety Institute, 40 hours, Chicago, IL

Asbestos Awareness Course
May 22, 2009, National Environmental Trainers Inc., Online Curriculum, 2 hours, Irmo, SC

CONTINUING EDUCATION, Continued

Electrical License Renewal Course
February 7, 2009, Asheville-Buncombe Technical Community College, 8 hours, Candler, NC

Advanced Fire, Arson, and Explosion Investigation Training Program
August 4-6, 2008, National Association of Fire Investigators, 24 hours, Sarasota, FL

Detailed Electrical Code Change Workshop
January 25, 2008, JCR Productions, Inc., 8 hours, Raleigh, NC

How to be a Successful Consultant and Get in on a Booming Market
November 10, 2007, Institute of Electrical and Electronics Engineers, 6 hours, Research Triangle Park, NC

National Electrical Code Continuing Education Correspondence Course
February 20, 2007, JCR Productions, Inc., 8 hours, Online curriculum
December 8, 2005, JCR Productions, Inc., 8 hours, Online curriculum

Detailed National Electrical Code Workshop
August 3 & 4, 2002, JCR Productions, Inc., 24 hours, Durham, NC
March 6 & 7, 1999, JCR Productions, Inc., 18 hours, Raleigh, NC

Current with the National Electrical Code
July 16, 2001, JR Sears, 6 hours, Raleigh, NC
March 18, 2000, JR Sears, 6 hours, Raleigh, NC

Structural Firefighting Operations
April 24, 2001, Wake Technical Community College, 3 hours, Raleigh, NC
May 20, 2000, Wake Technical Community College, 8 hours, Raleigh, NC
January 15 & 16, 2000, Wake Technical Community College, 16 hours, Raleigh, NC
August 11, 1999, Wake Technical Community College, 4 hours, Raleigh, NC
May 13, 1997, Garner Volunteer Fire Department, 3 hours, Garner, NC
April 26, 1997, Garner Volunteer Fire Department, 6 hours, Garner, NC
November 9 & 10, 1996, Wake Technical Community College, 16 hours, Raleigh, NC
October 29, 1996, Garner Volunteer Fire Department, 4 hours, Garner, NC
November 28, 1995, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
April 18, 1995, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
March 19, 1994, Lincoln Parish Fire Protection District No. 1, 7.5hours, Vienna, LA
March 8, 1994, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
January 25, 1994, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
May 1-2, 1993 Louisiana State University Firemen Training Program, 4 hours, Vienna, LA
March 14-15, 1993 Louisiana State University Firemen Training Program, 12 hours, Baton Rouge, LA

Emergency Medical Technician
January 30, 2001, Wake Technical Community College, 3 hours, Raleigh, NC
September 26, 2000, Wake Technical Community College, 3 hours, Raleigh, NC
June 27, 2000, Wake Technical Community College, 3 hours, Raleigh, NC
May 30, 2000, Wake Technical Community College, 3 hours, Raleigh, NC
March 28, 2000, Wake Technical Community College, 3 hours, Raleigh, NC
November 30, 1999, Wake Technical Community College, 3 hours, Raleigh, NC
November 10, 1999, Wake Technical Community College, 3 hours, Raleigh, NC
October 13, 1999, Wake Technical Community College, 3 hours, Raleigh, NC
August 31, 1999, Wake Technical Community College, 3 hours, Raleigh, NC
June 29, 1999, Wake Technical Community College, 3 hours, Raleigh, NC

CONTINUING EDUCATION, Continued

May 12, 1999, Wake Technical Community College, 3 hours, Raleigh, NC
February 10, 1999, Wake Technical Community College, 3 hours, Raleigh, NC
January 13, 1999, Wake Technical Community College, 3 hours, Raleigh, NC
July 22 - October 26, 1998, Wake Technical Community College, 126 hours, Raleigh, NC

Incident Command System

January 23 & 30, 2001, Wake Technical Community College, 6 hours, Raleigh, NC
December 8 & 22, 1998, Wake Technical Community College, 6 hours, Raleigh, NC
December 8 & 11, 1997, Wake Technical Community College, 12 hours, Raleigh, NC
February 7, 1997, Wake Technical Community College, 8 hours, Raleigh, NC
January 23, 1996, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
December 21, 1995, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA

Hazardous Materials Training

January 9 & 16, 2001, Wake Technical Community College, 6 hours, Raleigh, NC
March 1 - 16, 1997, Wake Technical Community College, 32 hours, Raleigh, NC
January 14, 1996, Wake Technical Community College, 3 hours, Raleigh, NC
January 7, 1996, Wake Technical Community College, 3 hours, Raleigh, NC
March 7, 1995, Louisiana State University Firemen Training Program, 4 hours, Vienna, LA
April 23, 1994, Louisiana State University Firemen Training Program, 4 hours, Vienna, LA

Fire Hose Handling, Fire Streams, Fire Appliances

November 15 & 24, 1999, Wake Technical Community College, 12 hours, Raleigh, NC
October 22, 1996, Garner Volunteer Fire Department, 2.5 hours, Garner, NC
May 20, 1996, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
May 7, 1996, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
May 9, 1995, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
May 2, 1995, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
March 21, 1995, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
January 11, 1994, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA

Passenger Train Emergency Response

January 16, 1999, Amtrak, 8 hours, Garner NC

Sprinkler Systems

February 2 to March 10, 1998, Wake Technical Community College, 12 hours, Raleigh, NC

Rescue Tool Operation / Vehicle Extrication

June 24, 1997, Garner Volunteer Fire Department, 2.5 hours, Garner, NC
February 11, 1997, Garner Volunteer Fire Department, 2 hours, Garner, NC

Pumper Operations

June 14, 1997, Garner Volunteer Fire Department, 1.5 hours, Garner, NC
April 2, 1996, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
October 24, 1995, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
October 3, 1995, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
February 7, 1995, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
January 11, 1995, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
December 6, 1994, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
November 8, 1994, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
April 12, 1994, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA

CONTINUING EDUCATION, Continued

September 10, 1993, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA

Foam Application
June10 & 11, 1997, Garner Volunteer Fire Department, 5 hours, Garner, NC
February 4, 1997, Garner Volunteer Fire Department, 2.5 hours, Garner, NC

Military Aircraft
April 19, 1997, Garner Volunteer Fire Department, 2 hours, Garner, NC

Municipal Water Supplies and Codes
April 8, 1997, Garner Volunteer Fire Department, 2.5 hours, Garner, NC

Personal Protective Equipment
March 11, 1997, Wake Technical Community College, 4 hours, Raleigh, NC
March 4, 1997, Wake Technical Community College, 4 hours, Raleigh, NC
February 25, 1997, Wake Technical Community College, 4 hours, Raleigh, NC

Fire Alarms and Communications
December 3, 1996, Garner Volunteer Fire Department, 1 hr., Garner, NC
November 5 - 7, 1996, Garner Volunteer Fire Department, 9 hours, Garner, NC
April 19, 1994, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA

Essentials of Firefighting
October 26 – 27, 1996, Wake Technical Community College, 16 hours, Raleigh, NC
April 22, 1994, Fire and Emergency Training Network Online Curriculum, 1 hour, Vienna, LA
March 8, 1994, Fire and Emergency Training Network Online Curriculum, 2 hours, Vienna, LA
March 7, 1994, Fire and Emergency Training Network Online Curriculum, 1 hour, Vienna, LA
February 2, 1994, Fire and Emergency Training Network Online Curriculum, 4 hours, Vienna, LA

Ladders, Ventilation, Forcible Entry
September 24, 1996, Garner Volunteer Fire Department, 1.5 hours, Garner, NC
May 21, 1996, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
January 20, 1995, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
October 24, 1994, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA

CPR for Certification
July 16, 1996, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
January 24, 1995, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA

Tanker Operations
June 18, 1996, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
June 4, 1996, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
September 22, 1994, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
September 15, 1994, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
September 13, 1994, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
September 8, 1994, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
August 30, 1994, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA

Self Contained Breathing Apparatus (SCBA), Search and Rescue
May 18, 1996, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
February 13, 1996, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
February 6, 1996, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA

CONTINUING EDUCATION, Continued

January 13, 1995, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
March 14, 1994, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
October 11 & 14, 1993 Louisiana State University Firemen Training, 12 hours, Vienna, LA
September 23, 1993 Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
March 22 & 25, 1993 Louisiana State University Firemen Training Program, 12 hours, Vienna, LA

Principles of Combustion
March 19, 1996, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
January 12, 1995, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA

Officer Training
January 18, 1996, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA

Fire Department Organization/Administration
January 9, 1996, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
October 11, 1994, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
September 27, 1994, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA

Arson Investigation
Fall 1995, Louisiana State University, Eunice, 3 Semester Hours, Vienna, LA

Property Insurance Association of Louisiana Grading Schedule
November 7, 1995, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
September 19, 1995, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
September 6, 1994, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA

Vehicle Fire Training
November 4, 1995, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
January 28, 1995, Lincoln Parish Fire Protection District No. 1, 4 hours, Vienna, LA
March 17, 1994, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA

Ladder Truck Operations
August 26, 1995, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
October 26, 1993, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA

Fire Cause and Origin Determination
February 28, 1995, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
February 21, 1995, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA
February 22, 1994, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA

Fire Extinguisher Training
March 22, 1994, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA

Salvage and Overhaul
February 7, 1994, Lincoln Parish Fire Protection District No. 1, 3 hours, Vienna, LA

Firefighter Safety and Survival
October 7, 1993, Louisiana State University Firemen Training Program/National Fire Academy, 12 hours, Choudrant, LA

COURSES, SEMINARS AND LECTURES PRESENTED

Forensic Fire Investigations
February 27, 2020, Durham Fire Department, Durham, NC

Electrical Fundamentals DVD
August 15-19, 2019, Mike Holt Enterprises, Orlando, FL

Rachel Rossoff Fatality at Heritage Point Pool
April 9, 2019, North Carolina Electrical Institute 90th Annual Meeting, Raleigh, NC

Spoliation of Evidence
May 2, 2018, North Carolina IAAI Annual Meeting, Burlington, NC

Lightning Effects on Dwelling Wiring and Gas Piping Systems
February 24, 2017, NC Insurance Crime Information Exchange, Winston Salem, NC

Electrical System Analysis in Fire Investigations
June 16, 2016, Myrtle Beach Fire Department, Myrtle Beach, SC

Forensic Investigations of Fire and Arc Flash Incidents
April 5, 2016, 8th Annual Duke Energy Engineers Day Event, Raleigh, NC

Arc Mapping
May 6, 2015, North Carolina IAAI Annual Meeting, Burlington, NC

Electrical System Analysis
May 6, 2014, North Carolina IAAI Annual Meeting, Burlington, NC

Electrical Fire Causes
February 22, 2012, University of North Carolina – Charlotte, ETFS 2126, Charlotte, NC
October 21, 2010, The Warren Group-Large Loss and Complex Claims Seminar, Irmo, SC
March 18, 2010, The Warren Group-Large Loss and Complex Claims Seminar, Irmo, SC
March 5, 2010, University of North Carolina – Charlotte, ETFS 2126, Charlotte, NC
February 23, 2010, The Warren Group-Large Loss and Complex Claims Seminar, Irmo, SC
February 12, 2010, University of North Carolina – Charlotte, ETFS 2126, Charlotte, NC
October 22, 2009, The Warren Group-Large Loss and Complex Claims Seminar, Irmo, SC
August 27, 2009, The Warren Group-Large Loss and Complex Claims Seminar, Irmo, SC

Residential Electrical Systems
June 26, 2012, South Carolina IAAI Annual Meeting, Columbia, SC
May 5, 2010, North Carolina IAAI Annual Meeting, Burlington, NC

Forensic Investigations
April 4, 2011 Southeastern Electric Exchange Annual Conference and Trade Show, Orlando, Fl

PUBLICATIONS

J. Cavaroc "Assessment of Stresses on Induction Motors Due to Momentary Service Interruptions" Ph.D. Dissertation, North Carolina State University, August 2007.

M. Baran, J. Cavaroc, A. Kelley, S. Peele, Z. Kellum "Stresses on Induction Motors Due to Momentary Service Interruptions" I&CPS Technical Conference, 2006, IEEE 30,05 April 2006. pp. 1, 8.

M. Baran, A. Kelley, S. Peele, J. Cavaroc "Zero Voltage Ride Through on Induction Motors" Power Systems World Conference 2002

A. Kelley, J. Cavaroc, J. Ledford, L. Vassalli, "Voltage Regulator for Contactor Ride Through" IEEE Transactions on Industry Applications, Vol. 36, No. 2, March/April 2000. pp. 697, 704.

A. Kelley, M. Harris, J. Cavaroc, M. Jones, R. Linkous, D. Hartzell, D. Darch, "Bus connector for Coordinated Interconnect: Laboratory Measurement and Finite Element Simulation" APEC 1999, Vol. 1, 14, 8, March. pp. 325 & 331.